MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

MARCH•APRIL 1999

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God's Eyes for Sale

Spy-quality satellite images will soon flood the market.

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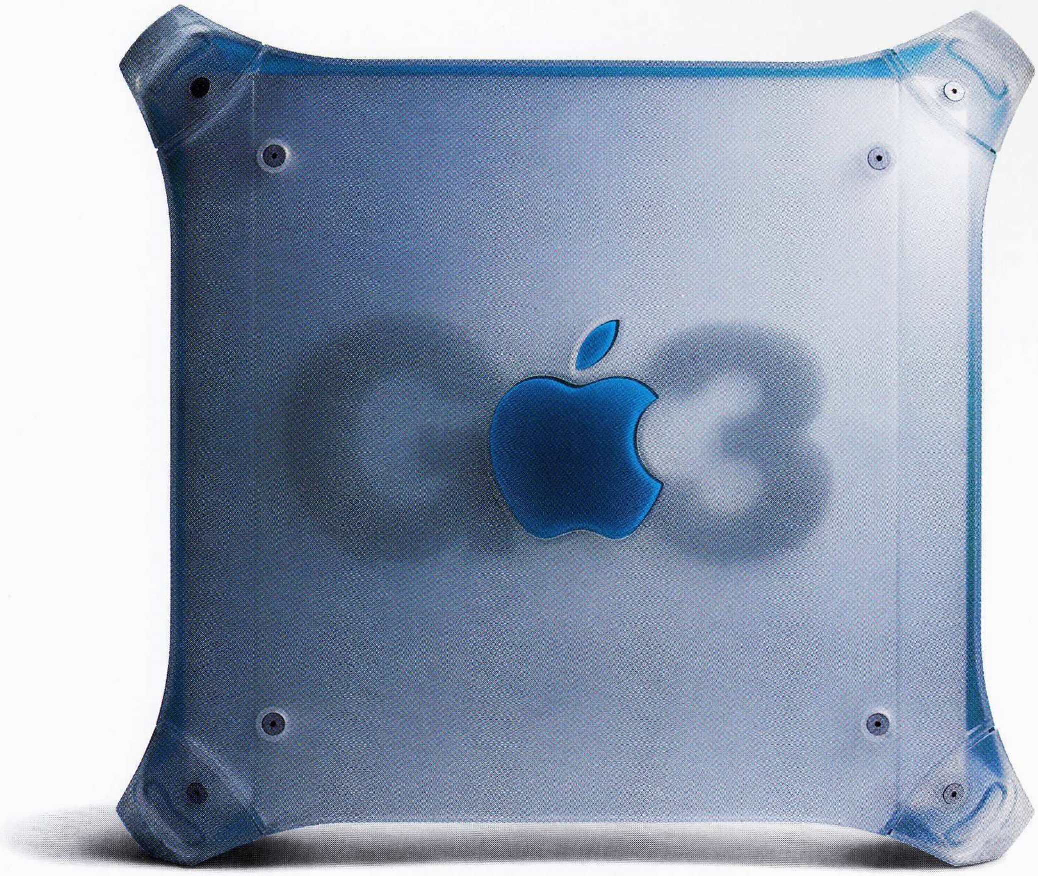

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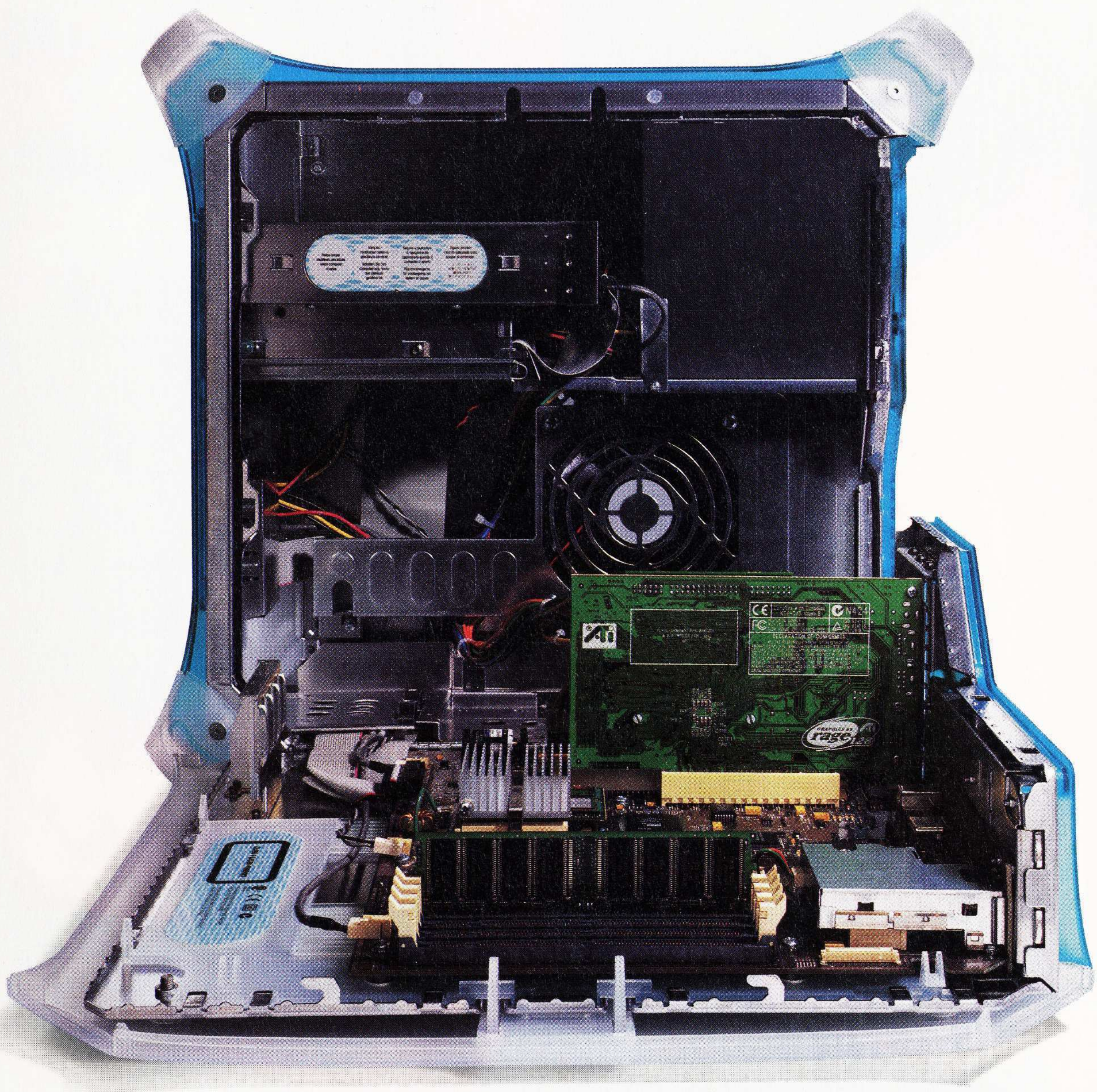

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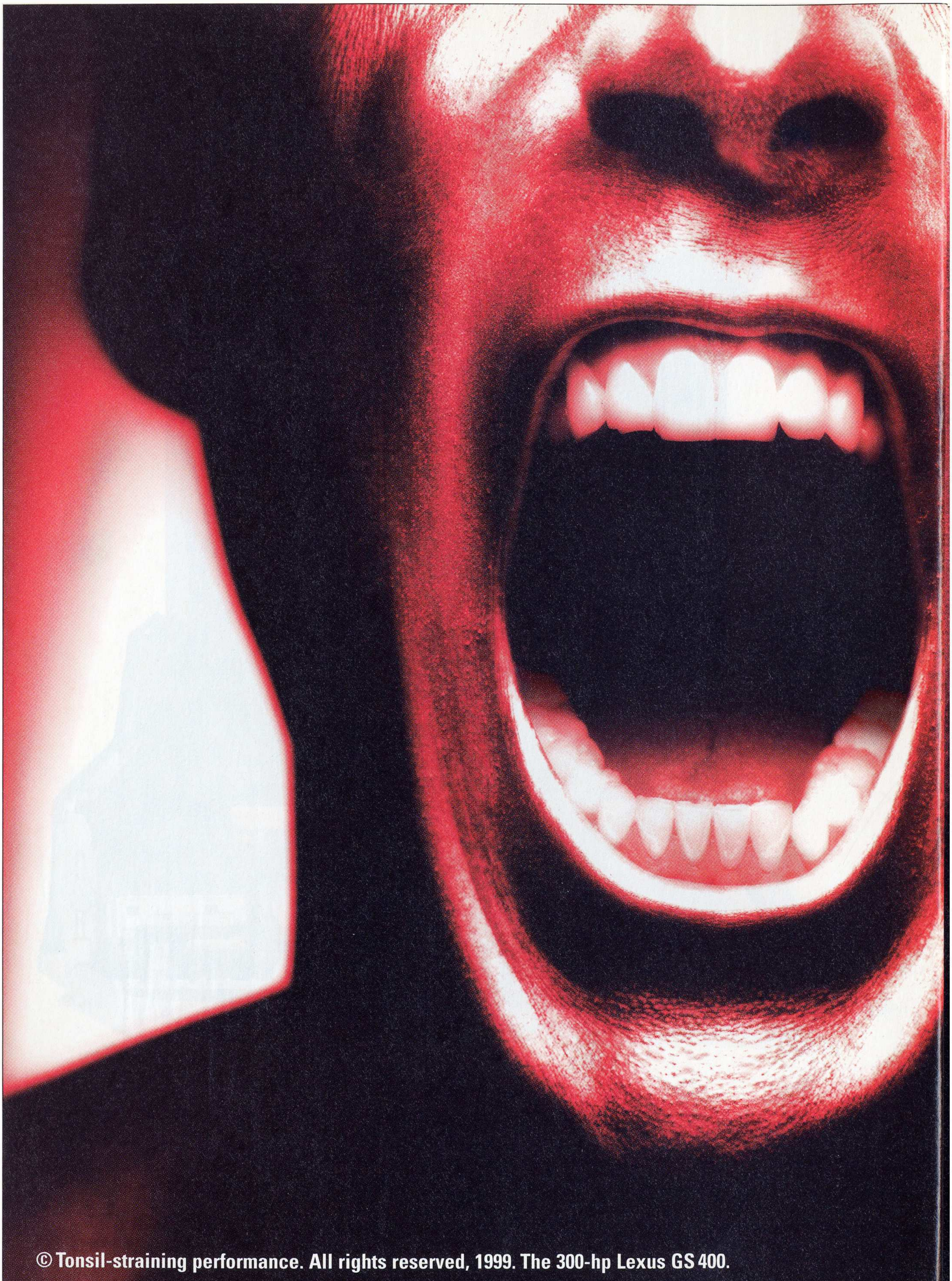
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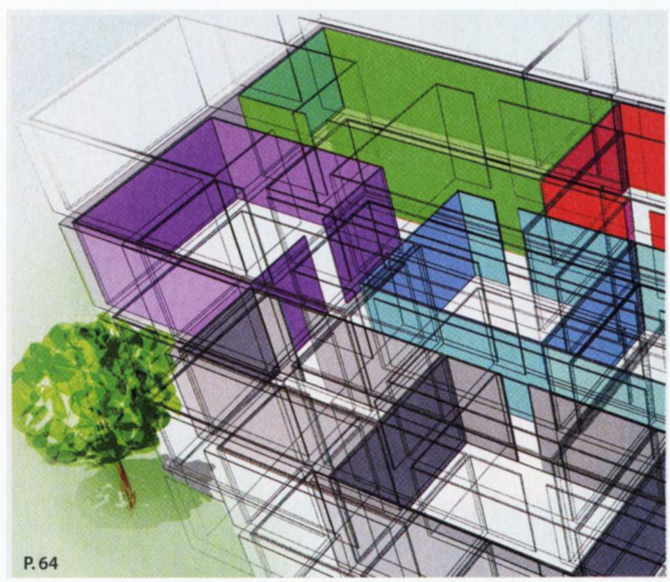

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Cover image by James Porto


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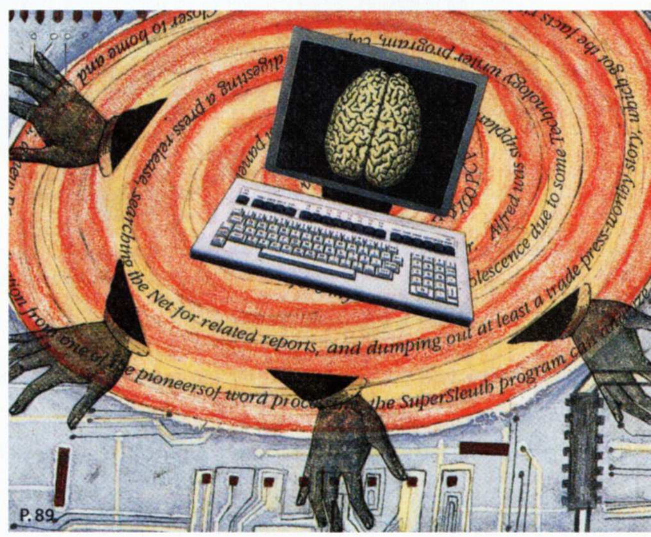
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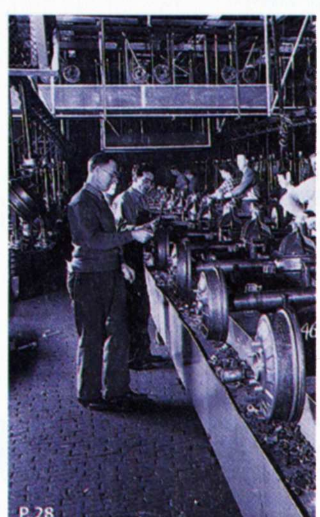
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INDEX People and Organizations in Our Articles

Nowhere to Hide

WHAT HAPPENS WHEN TECHNOLOGICAL CHANGE OUTRUNS SOCIETY'S CAPACITY TO keep tabs on it? Well, in the case of spy-quality satellite imagery, we're about to find out. Until just a couple of years ago, satellite images with a 1-meter resolution (you can distinguish objects 1 meter across in them) were the state of the art. They were largely in the hands of the intelligence agencies of the major powers, chiefly the United States and the former Soviet Union. But times have changed—with a vengeance. The breakup of the Soviet state and the end of the Cold War are about to loose a flood of these high-quality satellite images on the market, as Ivan Amato tells *TR* readers in this issue's cover story: "God's Eyes for Sale."

The first of these images hit the World Wide Web last summer, where they were offered for as little as $10 a pop. That was just a first taste. In the coming year, as Amato's fine reporting shows, half a dozen or more companies will launch their own satellites to provide consumers with the views once reserved for the spooks. These pictures will have plenty of legitimate uses. Real-estate agents can use them to show potential buyers new neighborhoods. Geologists working for oil companies will exploit them to identify "sweet spots" that harbor natural gas. Travelers can get a street-level view of Rome before arriving.

But there are plenty of potential users of this newly available information whose motives aren't so nice. First of all, some of the world's generals, from countries that can't afford their own spy satellites, will get access to this kind of information for the first time. Is that a good thing? Maybe. Some experts say more knowledge generally helps stabilize tense international situations. Then again, it might not. And beyond these implications lie even queasier scenarios. What would North Korea do with information showing San Francisco airports in fine detail? What will Saddam Hussein do with building-by-building pictures of downtown Tel Aviv? Experts say combining readily available data from the Global Positioning System and the new high-resolution images would make targeting missiles easier than it would otherwise be. And how about terrorist groups? The idea of providing them with better targeting information doesn't sit particularly well. Beyond the scare scenarios lie stubborn issues of privacy. What happens when almost anyone can look right down into your backyard, from high in the sky, without your knowing he's doing that?

One problem with these questions is that nobody knows the answers. This is definitely one of those situations where the flow of information, pushed by a variety of motives, is expanding much faster than our collective wisdom. In the case of the former Soviet Union, the motivation was probably the need for hard currency. In the United States, the Clinton administration, leaning toward the interests of the private sector, has established relatively few controls on the sale of these once-secret images.

Given the current pace of technological change, there are plenty of areas where knowledge is outpacing wisdom. But there aren't many where the stakes are quite as high as they are in the realm of spy-quality satellite data. It's time the administration and Congress took a careful look at what is going to happen as spy's-eye views enter the marketplace in abundance. This spring may be the last time they have a chance to do that before the deluge of images is upon us.

—John Benditt

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TECHNOLOGY REVIEW

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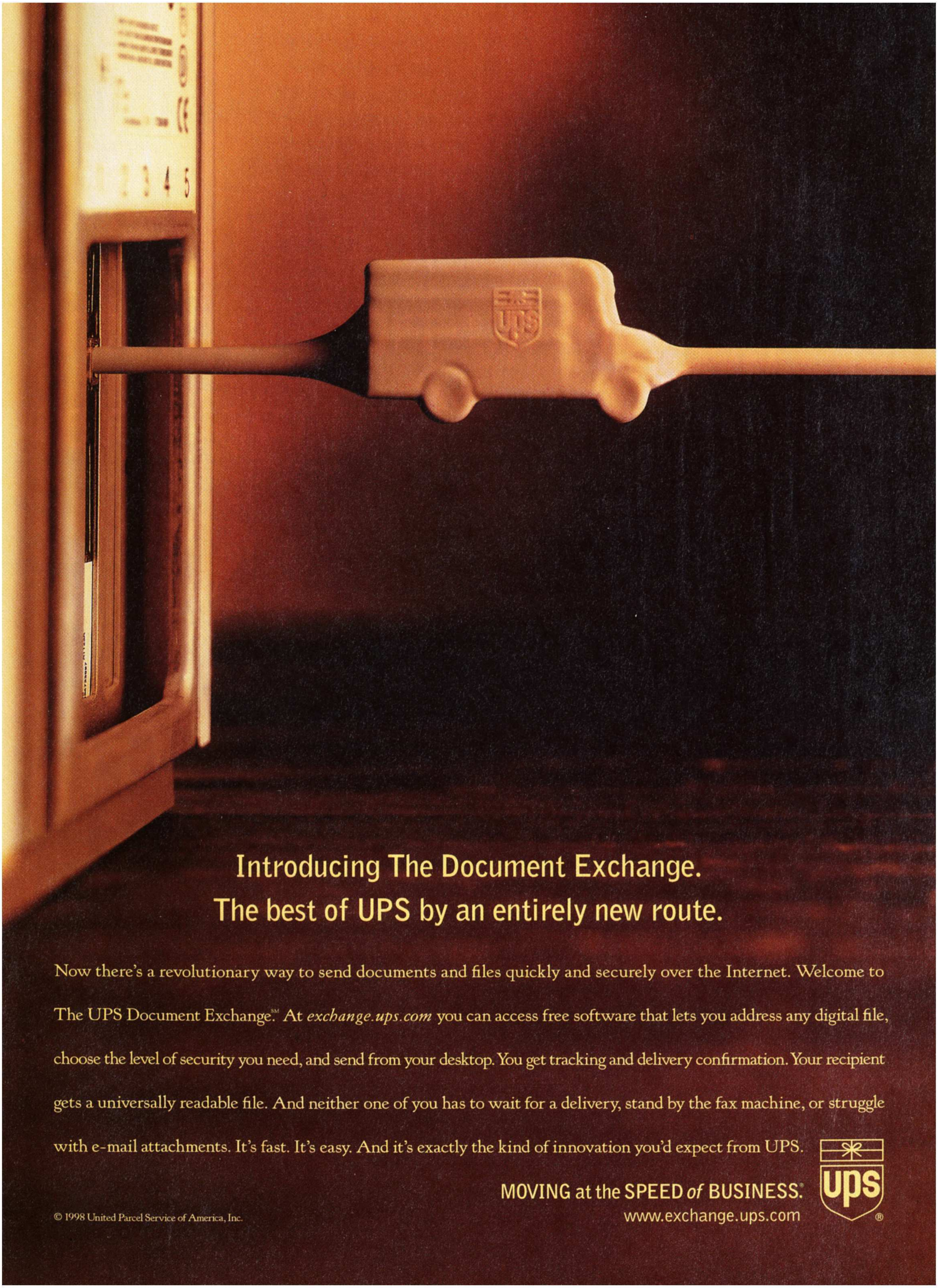
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VOICES *Contributors to Our Pages*

We live in a world of fast-paced technological change. That much, everybody knows. But which changes are important? What makes them possible? Who's behind them? From gene sequencing to wavelength multiplexing, this issue's feature stories exemplify *TR*'s commitment to answering those questions and getting to the bottom of technologies on the upswing. | **Ivan Amato** came up with the idea for the cover story "God's Eyes For Sale" after visiting a Web site hawking high-resolution satellite images with enticements such as "Click Through Baghdad!" Amato soon discovered that these former spy pictures not only ignore borders but can also reach right into our homes. The first satellite pic he viewed on line was of his Silver Spring, Md., neighborhood (to find your own, visit www.terraserver.com). Amato is a part-time correspondent for National Public Radio and the author of *Stuff: The Materials the World Is Made Of*, a chronicle of cutting-edge research in materials science. | Even satellite photos can't show the technological upheavals going on inside the fiber-optic networks that crisscross the earth and oceans. For that, we turned to **Jeff Hecht**. In "Wavelength Division Multiplexing" Hecht explains how engineers are doubling the information-carrying capacity of fiber-optic lines every year by tinkering with Nature's color palette. Hecht's expertise will be in full view come spring when Oxford University Press publishes his book *City of Light: The Story of Fiber Optics* (part of the Alfred P. Sloan Foundation's Sloan Technology Series.) Hecht is a correspondent for the U.K.'s *New Scientist.* | Just how fast is the genetic revolution moving? This fast: A gutted Maryland building that **Karin Jegalian** visited last fall is now the world's most prolific gene sequencing lab. Soon, Jegalian reports in "The Gene Factory," the company that built the facility may leapfrog the government-funded Human Genome Project in the effort to decipher all human DNA. Jegalian holds a PhD in biology and is a recent graduate of the science writing program at the University of California, Santa Cruz. | Most of our authors try to describe what's new in technology, but **Becky Waring** found two Berkeley professors who say that much of the frenzy surrounding online commerce is best explained the old-fashioned way: by well-established market principles. Waring explores their rules for the new economy in the Q&A starting on p. 80. Waring is managing editor of *NewMedia*, a trade publication for multimedia pros. | This issue's special report on nanotechnology takes a close look at the science of building and doing things at the most minuscule of scales. *TR* Senior Editor **David Rotman** provides an introduction to the field's promise (and overpromises) in "Will the Real Nanotech Please Stand Up?" Picking up where Rotman leaves off, **David Voss** describes the internecine feuding between scientific doers and dreamers in "Moses of the Nanoworld" and then hones in on a key technical challenge in "Chips Go Nano." Voss spent 12 years in the trenches at *Science* magazine where he was the senior editor overseeing manuscripts in the physical sciences. He recently left *Science* to pursue his "first love"—writing. We're very glad he's made the new *TR* one of his first freelance ports of call. TR

The TR 100

Call for

Panel of Judges
(Partial Listing)

David Baltimore
President, California Institute of Technology
Nobel Laureate

Al Berkeley
President, NASDAQ/AMEX

Michael Dertouzos
Director, MIT Laboratory for Computer Science

Robert Langer
Professor of Chemical and Biomedical Engineering, MIT

Robert Metcalfe
Inventor of Ethernet, founder of 3Com, *InfoWorld* columnist
Vice President of Technology, International Data Group

Arno Penzias
Chief Scientist, Lucent Technologies
Nobel Laureate

Phillip Sharp
Professor and Department Head, MIT Department of Biology
Nobel Laureate

Charles Vest
President, MIT

Larry Weber
President, The Weber Group

Ann Winblad
Co-founder and Partner, Hummer Winblad Venture Partners

William Wulf
President, National Academy of Engineering

John Yochelson
President, The Council on Competitiveness

In November 1999, *Technology Review* will mark its 100th year of continuous publication. To celebrate a century of technological innovation, we will publish a special issue of the magazine, focusing on "The TR 100." This is a group of 100 young innovators (whose 35th birthday falls on or after January 1, 2000) chosen for their potential to make major contributions to technological innovation in the future.

Because you, our readers, are the heart of the *Technology Review* community, we are asking you to help us find the TR 100. If you know a young person who you think has the capacity to influence innovation in the 21st century, we'd like to know who they are. You can send us a letter identifying them and telling us why you think they're qualified to join this elite group. You may also use the special nominating form posted on our Web site.
The nominations will be evaluated with the help of our distinguished Panel of Judges.

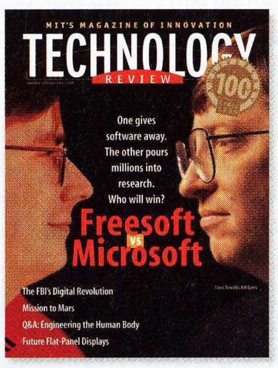
Deadline for submissions May 1, 1999

"Your article on GNOME is an excellent read...without the usual nonsense that passes for journalism these days."

GNOME

YOUR ARTICLE ON GNOME ("PROGRAMS TO the People," *TR* January/February 1999) is an excellent read, well-researched and well-written, without the usual nonsense that passes for journalism these days. But of course one can always find one nit to pick. You imply that before KDE and GNOME, there was no graphical interface for Linux. But the X Window System has been around for 15 years or so, and provides all the functionality of Windows or the Mac, plus customizability.

FELIX FINCH
via the Internet



THIS ARTICLE NEGLECTS TO mention that KDE had many more features and a smoother interface than GNOME. This also gives the false impression that the entire Linux community is behind GNOME and not that it is split between GNOME and KDE. In fact, some would argue that GNOME has a long way to go before it could ever become close to KDE.

TIMOTHY WHITFIELD
Ocean Springs, MS

I JUST WANTED TO SAY THAT YOUR ARTICLE "Programs to the People" is the best historical article about GNU/Linux I've seen, and I've seen a lot of them. I subscribe to a Linux-articles mailing list, which lets me know of most Linux articles from around the world. You covered the right bases, i.e. GNU, "OpenSource," Stallman, Torvalds and Raymond, and explained the different motivations, desires and politics of the players involved far better than any other article I've seen. Good job.

ED COGBURN
Greeneville, TN

BOTH GNOME AND KDE ARE IN PARTIAL CVS freeze right now in preparation for the next version releases. KDE looks like they'll probably get there first with KDE 1.1 and GNOME should be quite close behind with their 1.0. Charles, when both of these are out, please get yourself a Linux system (by whatever means you like) and install both these releases. Then use them both for a while and write an objective article comparing the two! Better yet, sit your granny down in front of them and see which one she likes the most. Personally, I am a huge KDE fan, and I'm sure that when you've done the above exercise, you'll find that you have a lot of very nice things to say about KDE. If you've never tried it before, you'll be surprised.

JOHN MCNULTY
Reading, UK

IN YOUR OTHERWISE EXCELLENT article on free software, you attribute the design of the GNU kernel to Richard Stallman and state that he "was one of the few people in the world up to the task of developing a radically new kernel." In fact I am the principal architect and developer for that system, called the GNU Hurd. I have been greatly assisted in this work by my excellent colleagues Roland McGrath and Miles Bader, but Richard Stallman has played essentially no role in the design or implementation of the Hurd.

THOMAS BUSHNELL, BSG
Cambridge, MA

CHARLES MANN MENTIONS "A TEST OF software reliability published last May, [by] seven computer scientists at the University of Wisconsin..." I am very interested in reading this study, but have not been able to track it down. Can you provide any more information on this study, e.g. the name of the lead author?

JOHN GANTER
Sandia National Laboratories
Albuquerque, NM

We welcome letters to the editor.

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Please include your address, telephone number, and e-mail address.
Letters may be edited for clarity and length.

THE ARTICLE STATES THAT "LINUX IS THE sole non-Microsoft operating system that is expanding its market share." I wonder if Mann wrote this in awareness, or ignorance, of the various free BSD variants (FreeBSD, NetBSD, and OpenBSD). I had the impression that they were gaining as well. I assume that Mr. Mann researched this, and so I am curious what numbers he turned up. (Also, is "market share" a ratio of the total market, or is it a number of installed systems?) A tip of the hat to the other free UNIX-alikes would have been worth at least a short sentence, surely, if for no other reason than to clarify how they stand.

RICHARD RAUCH
Lawrence, KS

Charles Mann responds:
I apologize to Thomas Bushnell for misattributing the Hurd to Richard Stallman. When I asked Stallman about his importance to the Hurd, he said he didn't deserve the credit for it, which I misunderstood as modesty. The software reliability study is called "Fuzz Revisited: A Re-examination of the Reliability of Unix Utilities and Services," by Barton P. Miller of the University of Wisconsin computer science department and 6 UW coauthors. Richard Rauch wonders where the data on Linux market share came from. Market share for operating systems is, as he suggests, difficult to evaluate. I relied principally on the surveys from IDC, which have a good reputation. Because the market shares of the other free-software operating systems are generally too small to track reliably, they may be growing beneath the radar of the surveys, as Rauch suggests. Finally, KDE announced after my article went to press that version 2.0 will be open-source compliant, removing many programmers' principal objections to it.

Digital Have-Nots

I AM IMPRESSED WITH MICHAEL DERTOUZOS' column ("The Rich People's Computer?" *TR* January/February 1999)

because he is one of the few westerners who really "get" the issue of information access in a developing country.

At MIT, I have been attending a lot of seminars and talks by some of the gurus of the digital age and am constantly astonished by their naivete when it comes to this issue. One famous speaker was asked for his views on the digital have-nots and his answer was that he was more worried about the 56-year-olds in Congress (the American Congress, of course!) who did not understand technology. This from a man who claims to have cumulatively spent around six months over the last ten years in Africa! The common assumption here in the United States is "The market will take care of it!" In India, for example, almost 95 percent of the population (around 855 million Indians!) has no chance of using a computer with Windows because it is available only in English, which is spoken by a mere 5 percent of the population.

America's role in making computers accessible to the other 99 percent of the world is important because the vast majority of information technology is developed here. It is therefore nice to note that a technology leader like Dertouzos is aware of the seriousness of this issue. There is some hope for the rest of the world!

VENKATESH HARIHARAN
Knight Fellow, MIT
Cambridge, MA

I THINK MICHAEL DERTOUZOS FORGETS that even a journey of a thousand miles begins with a single step. He speaks about wanting to boost Nepal's economy by 20 percent through the information marketplace, but being stalled by many problems, chief among them Nepal's 27 percent literacy rate. The 27 percent of the population who are literate aren't all skilled, and those who are skilled are already involved in businesses. Simply focusing on selling Nepalese crafts on the Web raised other problems. In the end, Mr. Dertouzos raises the specter of "the ancient forces that separate the rich from the poor."

I don't know much about ancient forces, but I do know that illiteracy has a cure: Teach people to read. Teaching people to read is a low-tech solution, but readers can learn other things—like how to put together a catalog of their own crafts, see how that enterprise goes, get their own computers, and go online.

NATALIE SEGAL
Ward College of Technology
University of Hartford
Hartford, CT

THE REVIEW OF THE "INFORMATION GAP between rich and poor" by Michael Dertouzos was a useful examination of possible solutions to this worldwide problem. One of the most obvious ways to involve the poor in the information marketplace is to take advantage of the short lifespan of today's PC products. Since we (the rich) are encouraged to upgrade our hardware every few years because of the manufacturers' seemingly endless improvements, there exists a wealth of scrapped computers which would be useful to first-time users who cannot afford to purchase. The only problem would seem to be distribution of these obsolete products to the needy. Mr. Dertouzos mentioned the level of illiteracy among some of the world's poor but I would suggest that if computers, obsolete as they may be, can be delivered into willing hands, that in itself may be an incentive to literacy. After all, given an automobile, a novice will usually find

the incentive to learn its operation and I'm sure we would not claim that a computer is more difficult to use than a car...just possibly more dangerous!

George Dunbar
Scarborough, ON

Car Culture

In an article on modern-day Luddites ("Ludd's Choosy Children," *TR* January/February 1999) Daniel Akst writes "our friends in L.A....drive cutting-edge cars through a web of sophisticated traffic signals, architecture and engineering to reach health-food stores where they escape modern farming technologies by 'buying organic.'" Since when did concern for health and the environment become an example of Luddite behavior? Perhaps Akst is one of those people who believes that the most technologically advanced solutions should always be embraced regardless of merit, an attitude which most certainly is more ridiculous than that of the Luddites. Like all forms of change, technological innovation involves tradeoffs. One need only consider the negative aspects of the so-called car culture (pollution, global warming, decline of the inner city, etc.) or the cognitive and cultural consequences of a nation glued to the inanities of prime-time television to see that technology can be a two-edged sword. "Selective Luddism" probably has less to do with "people's natural need to grope their way into tomorrow" and more to do with the sophistication that has come with a century of intensive technological change.

Patrick Goetz
Austin, TX

Red Planet

Jim Oberg's article "Missionaries to Mars" (*TR* January/February 1999) shows that the primary obstacle to human missions to Mars is neither scientific rationale nor technical challenges—we know why we want to go to Mars and how to get there—but political apathy. The Cold War competition that funded Apollo is gone and similar circumstances are unlikely to return; thus space is politically not a major issue for the President and Congress. Yet even the modest mission costs proposed in the article require significant political support and leadership from the United States and any other participating nations. The toughest task that the Mars Society and its members may face is effectively communicating their vision of human exploration of the Red Planet to the public and to the political leaders of the world.

Jeff Foust
Editor, SpaceViews
Cambridge, MA

James Oberg wants to send people to Mars. His article was 100 percent about the required technology, with not one word about potential benefits to us non-involved earthlings. (Of course there are many benefits to the scientists and engineers involved in the project.) I remember almost 20 Apollo flights, the first U.S. space station, then MIR, and 91 flights of the space shuttle. From all this I cannot remember a single benefit for the public. I sense that there are no benefits. Why not cancel the space station and all other manned space flights? Every benefit of space (satellites for communication, navigation, spying, etc.) comes from unmanned launches, which should continue.

Donald W. Smith
Hockessin, DE

Nullifying Nitrates

Steer clear of nitrates. These nasty waste compounds generated by the industrial use of nitric acid can cause blue baby syndrome in healthy infants or turn a healthy lake into a putrid marsh. Current methods for removing nitrate wastes from groundwater are energy-intensive, expensive, and not always effective. To improve this picture, researchers at the Los Alamos National Laboratory are testing an inexpensive process for converting solid and liquid nitrate wastes into harmless nitrogen gas. Wastewater is pumped through a chamber containing a re-usable metallic catalyst and an acid. The catalyst strips away the oxygen atoms from the nitrates, yielding nitrate-free wastewater and nitrogen gas. Los Alamos is testing the process on 10 different kinds of nitrates and has been inundated with calls from interested mining, chemical, farming and nuclear-power companies.


IBM RESEARCH

Flat display (front) outshines a CRT.

Picture Perfect

As millions of bleary-eyed computer users can attest, words and images on a screen are not nearly as sharp and crisp as those in, say, *Technology Review*. But IBM researchers in Yorktown Heights, N.Y., have built a display with a resolution of 200 pixels per inch—four times the resolution of the best commercial liquid crystal and cathode ray tube displays—that achieves a clarity rivaling the printed page. From a distance of about 45 centimeters, the screen's resolution closely approaches most people's limit of visual acuity.

IBM says commercialization is still a year away. Initial targets will be applications in which high resolution is critical, such as monitors for displaying x-rays and for publication design and production. But the computer giant expects eventually to make the flat-panel monitors available for mass-market computers.

Fire Sight

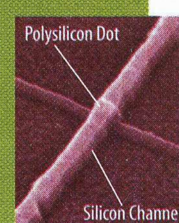
Rushing fearlessly into burning buildings, firefighters seem at times like superheroes. If researchers at a company called Zybron have their way, firefighters will actually acquire a superhuman power: the ability to see through a wall of fire that might conceal someone in need of rescue.

Zybron and other firms have already built devices that use infrared detectors to peer through thick smoke. But a fire's bright light and searing heat blots out the weak infrared signal given off by a human body on the other side of the flames. So Zybron, based in Beaver Creek, Ohio, is developing a helmet-mounted system that uses a diode laser to beam out light at a wavelength outside the spectrum of fire. The light bounces off objects behind the fire and back into a detector on the helmet; filters that pass only the laser's wavelength permit the system to create an image of the hidden area, which the firefighter views on a liquid crystal display attached to the visor. Zybron hopes to begin field tests late this year.


PHOTO DISC

Solo Flight

Semiconductor makers have supplied ever-more-efficient chips. But performance limits may soon be reached, partly because of the difficulty of making transistors small enough. Conventional transistors switch on or off when a burst of current passes through. As the transistor gets smaller, so does the level of current required. For the smallest of the small, labs have made transistors that switch in response to a single electron—but such nanodevices have required cryogenic cooling. Now Princeton electrical engineer Stephen Chou has created a single-electron memory that works at room temperature. Manufacture of such devices, however, is several years off, awaiting greater understanding of the chips' unusual properties.



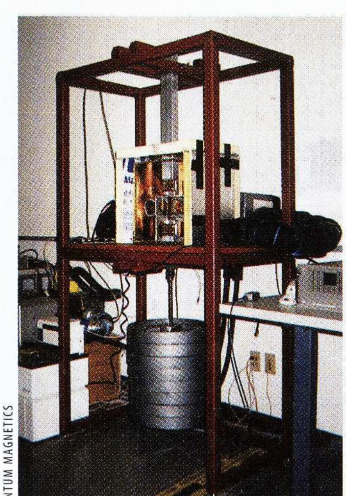
STEPHEN CHOU

One electron is enough.

Sense of Strain

Magnetic resonance imaging reveals unusual strain in a human body. Now a related physical effect, called nuclear quadrupole resonance, may help check for strain in the composite materials that are becoming common in everything from bridges to airplanes. The method, being developed by San Diego-based Quantum Magnetics, requires an undisclosed additive to be mixed into the composite as it is being formed. When this substance is hit by radio waves, it emits a different frequency; the magnitude of the shift indicates the strain in the material.

In one potential application, radio devices could be permanently affixed to various points on a structure to check the strain continually. Alternatively, a mobile unit could check for strain at particular points during routine maintenance. A commercial strain-monitoring system is about two years off, says researcher Stephanie Vierkotter.


QUANTUM MAGNETICS

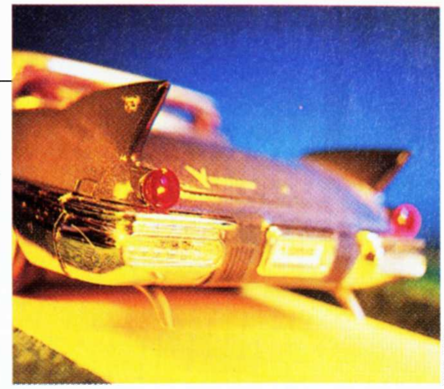
Probing for pressure.

MICHAEL P. MAHER

A Case of Nerves

It's the mystery of the brain: How do billions of cells conspire to create memory, reason and desire? To pick apart how a network of neurons functions, researchers at the California Institute of Technology have created a hybrid of living cells and silicon they call the "neurochip."

The device consists of 16 wells etched from silicon. Each contains an electrode and is just big enough to hold a single neuron from a rat brain. Axons can grow out and establish connections to the other cells in the array. To study the neurons' complex group behavior, researchers can stimulate any cell and then monitor the electrical responses of the rest of the network. Physicist Jerome Pine, who created the neurochip with postdoc Michael Maher, says that such a neurochip-type device could ultimately serve as a hi-fi interface to a living nervous system; a chip implanted in the brain would replace electrodes taped to the scalp as a way to send and receive signals.



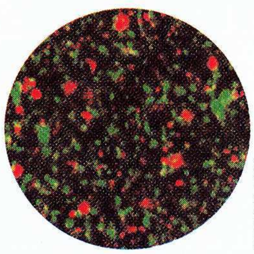
VITO ALUIA

Laser-Lit Cars

Engineers at Ford Motor Co. say taillights lit by lasers could lead to safer, more energy-efficient and better-looking automobiles. In an experimental design, fiber optics carry red light from a diode laser to a series of mirrors, which send the beam cascading across a 5-millimeter-thick sheet of acrylic. Reflective and refractive ridges direct the light outwards.

Because they consume one-seventh the power of incandescent bulbs, lasers could prove useful in electric vehicles, says Ford lighting engineer Michael Marinelli. The thin acrylic would also allow designers to mold lights around contours. And since lasers flick on nearly instantaneously, Marinelli calculates drivers could see a car braking 0.2 seconds earlier, cutting highway stopping distance by 5 meters. Laser headlights are on the drawing board—but await development of cheap, powerful blue diode lasers.

Bacterial Buffer



THOMAS K. WOOD

Biofilm prevents corrosion.

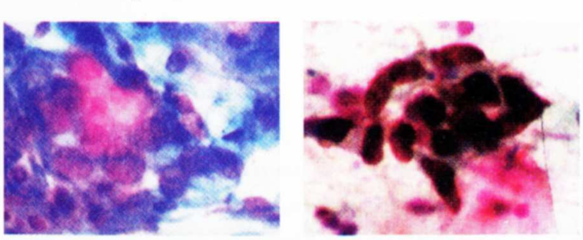
Leave water in contact with metal for any length of time and you've got a problem. Slimy bacterial colonies, or biofilms, form on just about any surface under water and corrode metal surfaces. One kind of sulfate-reducing bacteria can cause pitting even on stainless steel. But researchers at the Electric Power Research Institute (EPRI) in Palo Alto, Calif., have found that certain bacteria actually inhibit corrosion. These "aerobic" species not only consume the oxygen that corrodes metal; they also secrete proteins that suppress bacterial growth.

These bacteria could form the basis of new corrosion-resistant coatings that would have a big advantage over conventional paints: if scratched, a bacteria-based coating could repair itself. EPRI is testing this method in a cooling-water system at the University of California at Irvine. If it works, EPRI plans to try to genetically engineer bacteria for corrosion protection. As the research arm of the electric utilities, EPRI has a strong financial incentive: corrosion costs the U.S. electric power industry $5–10 billion per year.

Better Cancer Catcher

U.S. clinicians perform more than 50 million Pap smears each year to screen women for cervical cancer. But the test, which involves microscopically examining cells from the cervix, misses a notoriously high proportion (estimates range up to 40 percent) of abnormalities. Cambridge University researchers have devised a new screening tool that they hope will cut down on these missed opportunities to catch cancer while it's still curable.

The tool is a stain that selectively marks proliferating—thus potentially cancerous—cervical cells, making them readily visible among their nondividing normal counterparts. In small preliminary tests, the new stain helped researchers catch cervical abnormalities with 100 percent efficiency. The Cancer Research Campaign, the British charity that funded the research, has licensed the stain to Santa Clara, Calif.-based diaDexus. The company expects to have it on the market "within a couple of years."



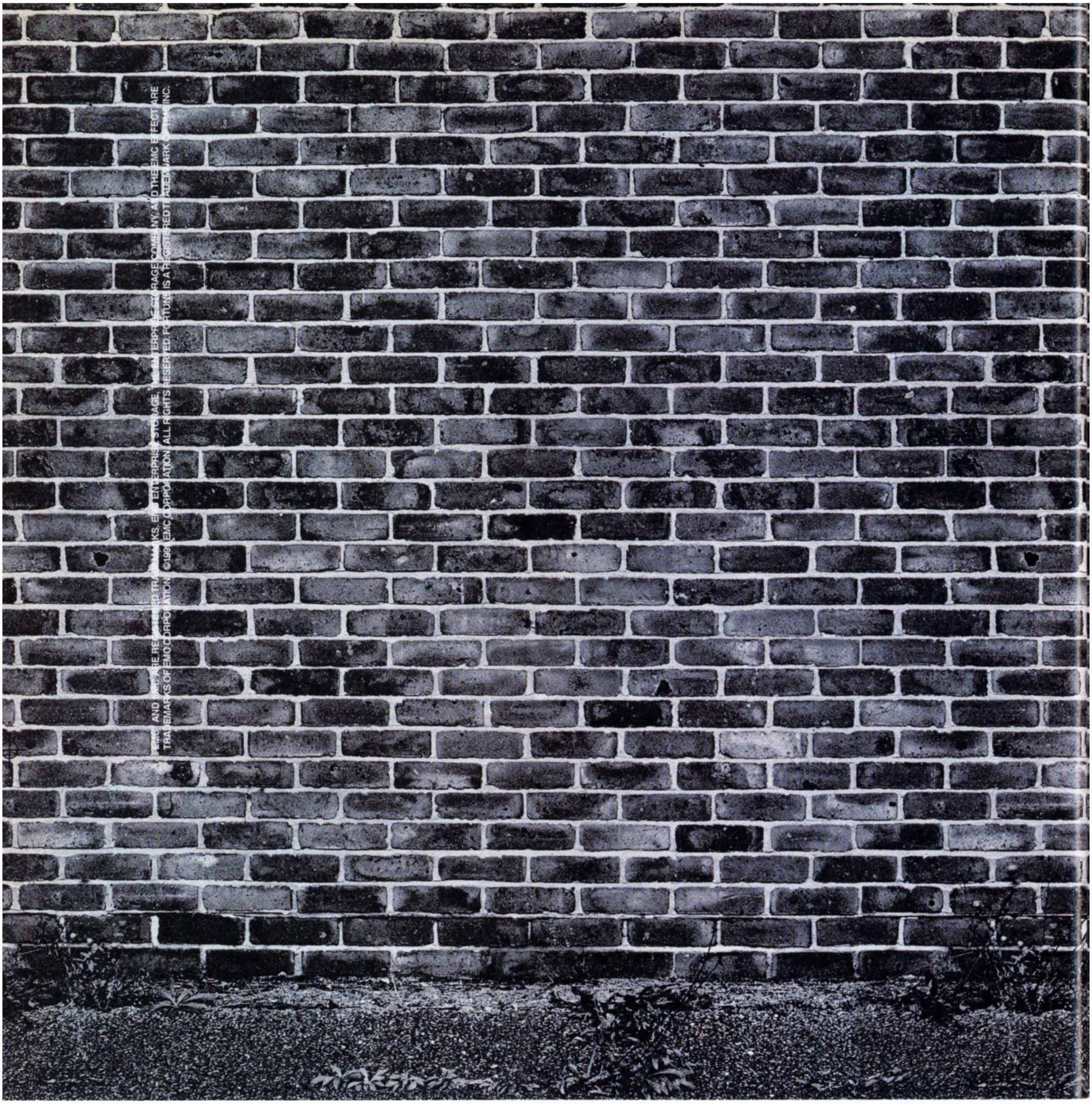
DIADEXUS

In a standard Pap test (left), abnormal cervical cells can blend into the background. The new stain (right) makes them stand out clearly.

GaAs Powered

Research at Lucent Technologies' Bell Laboratories in Murray Hill, N.J., may be hastening the onset of a new era in electronic materials. Scientists have long known that electrons travel much faster in gallium arsenide (GaAs) than in silicon. But GaAs has found limited use in computing devices, partly because of the difficulty of fabricating suitable transistors.

Silicon chips use metal-oxide-semiconductor field-effect transistors, or MOSFETs. Most GaAs devices now in use (principally in wireless communications) are MESFETs, lacking the oxide. To tap the advantages of GaAs fully will require MOSFETs, which use less power. Bell Labs took the first step two years ago, but its prototypes were woefully inadequate—current fluctuated by 20 percent over a few hours. In the new GaAs devices, however, current drifts only about 1.5 percent after 200 hours. One key benefit: longer time between cell phone rechargings.



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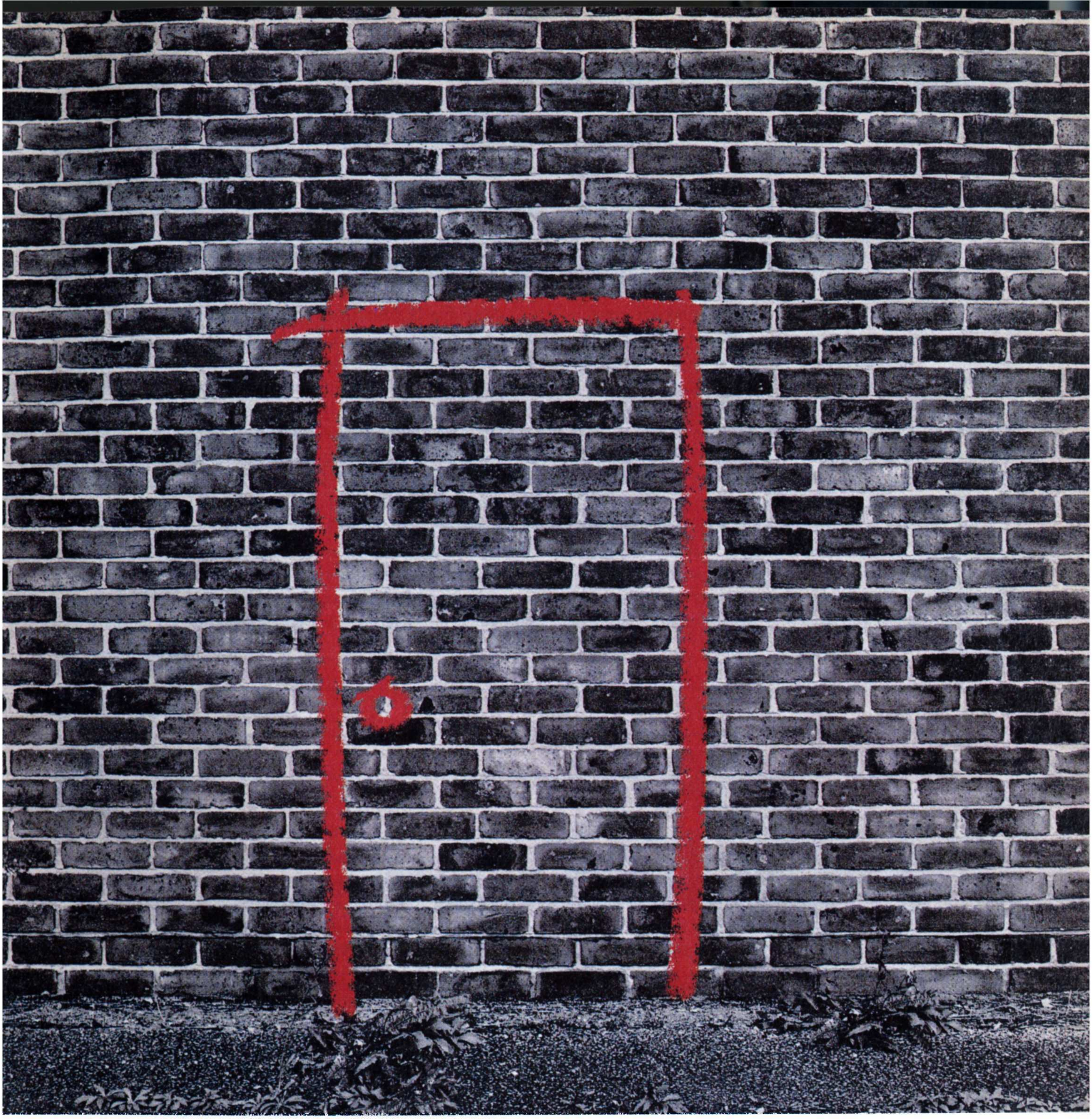


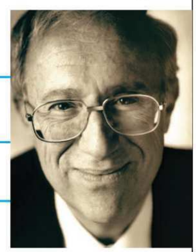
Why 2K?

Last Thanksgiving weekend, CBS's "60 Minutes" closed their program on the year 2000 problem with me saying: "I think we'll have a few pretty bad situations, but not the catastrophes that the panic-creating people are talking about. The problem, deep down, is that nobody knows."

Most people would prefer a mesmerizing revelation to such a bland conclusion. All the more so, since this event does not have an imagined deadline, like most mystical predictions, but is guaranteed to happen on January 1, 2000. No wonder we constantly hear about it, and no wonder most stories spin scarier than a typical apocalypse.

Just in case you haven't heard, Y2K, as it is abbreviated, is the result of frugal programmers having allowed in old programs only two characters, like 98, to describe 1998. Computers still running such programs will represent the year 2000 as 00, and will run into trouble—they'll compute 2000-1998 as -98...and may, as a result, ignore or cancel your two-year-old life insurance policy. Y2K troubles predicted by the media and by experts include failures of emergency medical equipment, shutdowns of water and power systems, malfunctions of air traffic control systems, faulty elevators and traffic lights, litigation that may total $700 billion, a collapse of the world's financial system, and much more. Survivalists are already moving to the country, with ample supplies, to weather the expected disasters. And normal folks are, predictably, scared.

Why didn't we see the problem coming? We didn't think the old programs would last and we were too excited developing future applications. In other words, we blew it!



How did we get into this problem? Through gradual addiction. From laboratory curiosities, computers became increasingly important to people as they took over credit cards, payroll, word processing, and in their small-chip forms the control of automobile systems, elevators, home appliances and many other mechanisms in which they are embedded. Eventually computers became so intertwined with our lives that today, a widespread computer malfunction like Y2K can affect all of us. Why didn't we see the problem? We didn't think the old programs would last and we were too excited developing future applications. In other words, we blew it!

Regardless of its origins, the Y2K problem is real. To understand its reach, imagine that on January 1, 2000 one piece of paper in every file cabinet in the world will be suddenly destroyed. Some papers will be vital. Most will be worthless. No one knows how such a bizarre incident would affect the world. That's pretty much the situation with Y2K. But ignorance has rarely stopped opinion from flowing. And since most of that opinion has involved hype and scary messages, I'll try to balance things out by applying my own ignorance of what will happen...in the other direction.

Most big organizations have already taken corrective action: Typically, they turn their computer clocks to January 1, 2000, and test their programs to discover, assess and correct failures. Organizations that offer critical products and services have been particularly vigilant, because of fear of litigation. And regulatory organizations, feeling the public pressure, have been pressing their constituents to ensure Y2K compliance. Unfortunately, not all of these organizations will be compliant by the end of the century, and some, especially outside the United States, will not be so. Nevertheless, by century's end, a substantial and widespread organizational corrective effort will have been applied to the Y2K problem.

Next, keep in mind that only a small fraction of the world's computers are engaged in critical applications. While advising a major international bank, I decided to assess the relative importance of their information systems. So, I asked the staff to stop issuing all 1,200 different kinds of monthly reports they sent to their thousands of employees, and, instead, provide individual reports if and when asked. You can imagine everyone's surprise when after a month, only six people had called for any of the reports. Alternatively, try to imagine how many of the 100 million people using personal computers to do word processing will experience a catastrophe if their computer clocks are suddenly turned to the year 2000. Still not convinced? Let's go back to all the file cabinets in the world: How much would you pay to not have them delivered to your front lawn? Let's face it. The bulk of information out there is not as vital to your life as the hype would like you to think.

Granted all that, there will still be Y2K problems that have not been corrected and that you consider important. What happens then? In the United States, we have 70 million office workers. This massive "information processing" human force will not be sitting on its thumbs, admiring Y2K problems as they develop. They will go to work, writing checks, switching to other, safe computer programs and devising all sorts of procedures to tackle difficulties, as they are identified.

Still, a few Y2K problems *will* penetrate defenses...and get us. Of these, a few will inevitably be bad. Most, however, will be simply annoying. Any bets on how many newspapers, magazines and TV programs will still be hyperventilating about Y2K in the new millennium? ◊

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JAMES STEINBERG

INFOTECH

Quantum Codebook

A Heisenbergian cipher nears practicality

As commerce rushes online, the ability to send private messages over public communications networks has become vitally important. The most secure means of encryption is for both the sender and the recipient of a message to use the same long string of random digits—known as a key—as the basis for encoding and decoding. But such a key must be exchanged, and whether the hand-off takes place via telephone, armored guard or carrier pigeon, there is always a risk of interception.

Well, almost always. Years ago, physicists came up with an approach called "quantum cryptography" that relies upon the bizarre laws of quantum mechanics to definitively shut out snoops and transmit key data in absolute security. IBM physicist Charles Bennett and his colleagues built the first working laboratory prototype in 1989. Now, researchers at IBM Almaden Research Center in San Jose, Calif., have built a device out of off-the-shelf telecommunications components that they say will soon move quantum cryptography out of the physics lab and into the real world.

Dubbed the "quantum cryptolink," the IBM device encodes bits of key information into individual photons of light by polarizing them in one of two directions. Users can exchange the data-bearing photons across a fiber-optic cable over short distances. Security is guaranteed by Heisenberg's uncertainty principle, which says it's impossible for an eavesdropper to observe the photons without disturbing them. If the sender and legitimate recipient see signs of spying, they can throw out all or part of the key and try again.

To build the cryptolink, a team led by Nabir Amer, manager of IBM's quantum information group, had to solve a number of practical problems. For instance, they implemented a signal-processing scheme to cancel out the errors that real-world fiber-optic networks introduce and which can leave a foothold for eavesdroppers to pilfer photons undetected. The biggest remaining challenge, according to IBM team member Bill Risk, is the ultra-sensitive photon detectors that must be chilled with liquid nitrogen to -173 C. Risk says new detectors cooled thermoelectrically should solve the problem.

By year's end, Amer estimates, his lab will engineer "a prototype of a card you can plug into a network." Although IBM doesn't yet have specific plans for commercializing the cryptolink, Amer says it might be used to provide secure islands on corporate or government computer networks, or to protect citywide networks of automated teller machines.

But Tom Parenty, director of data and communications security at Emeryville, Calif., software firm Sybase, says that "even though quantum cryptography may offer 100 percent secure communication, my feeling is that it's overkill for 99 percent of applications." Standard cipher systems, some of which don't require secure key exchange, can already ward off all but concerted attacks backed by massive computing power.

Amer believes that such ciphers could be rendered useless by another device in the works at IBM—the quantum computer. "If we ever have a quantum computer," says Amer, it would compute fast enough to crack today's codes "in a jiffy," and only its cryptographic equal could ensure safe communication.

—Antonio Regalado

INTERNET

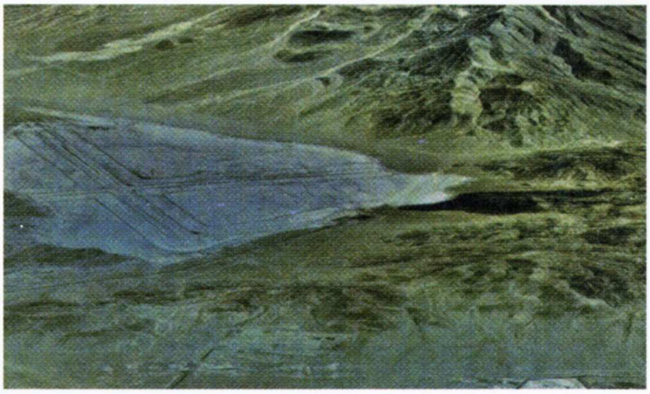
Think Globally, Act Digitally

Fly the Web to really get somewhere

EVER WONDER WHAT IT'S like to be a bird? A new terrain visualization system called TerraVision II allows you to "fly" over the surface of the earth—via your computer screen. Okay, it's not *exactly* like being a bird. It might be better, in fact, since a bird can't overlay road maps and infrared imagery or click on an interesting building to pull up its Web site.

Researchers at SRI International in Menlo Park, Calif., created TerraVision II, a specialized World Wide Web browser, to navigate through representations of actual terrain based on U.S. Geological Survey elevation maps, aerial images and other information. Potential applications of the system include military planning and combating natural disasters such as forest fires.

TerraVision is exciting stuff: A peek at the system's predecessor in the spring of 1997 apparently inspired Vice President Al Gore's speech "The Digital Earth," in which he called on scientists to create a digital model of the earth to a resolution of 1 meter. Assigning one pixel to each square meter of the globe, however, would require memory in excess of 10^{15} bytes (1 petabyte, or 1 million gigabytes)—still outside the capabilities of today's computers. Yvan Leclerc, senior computer scientist at SRI's Artificial Intelligence Center, explains that TerraVision II is an initial attempt to create the software and data repositories needed to create the digital earth.



SRI INTERNATIONAL

TerraVision II is an initial step toward virtual travel.

The first job SRI engineers tackled was developing algorithms to convert geographic data, such as satellite images, into Virtual Reality Modeling Language, a standard computer code used to describe 3-D objects on the Internet. They also needed to find ways to store all the data and retrieve it fast enough to create a continuous "flight." To solve the storage problem, Leclerc says, the plan is to keep data on servers at many locations. TerraVision browsers could call up data from the servers and convert it into images.

To move the massive amounts of data around rapidly enough to be useful, TerraVision II relies on a high-speed network supported by the Defense Advanced Research Projects Agency (DARPA). The U.S. military is also backing TerraVision, hoping for a system that can display "real time" data—actual weather or a moving column of tanks.

That goal is far off, but other applications could be around the corner for TerraVision II—such as virtual tourism. When planning a trip to Egypt, Leclerc imagines, "You can go up to the pyramids, look at them, walk around them, and then say, 'Yeah, I really like this, I want to do it now for real.'"

—Deborah Kreuze

BIOTECH

Ethics for Hire

Last November, Advanced Cell Technology, a biotechnology company based in Worcester, Mass., wanted to let the world know that it had created a human embryo using a cow's egg. Their vehicle of choice? The front page of *The New York Times*. "We weren't trying to be sensational," CEO Michael West says of the news leak; the company was merely trying "to get a reading on the public's acceptance." But sensation was exactly what West generated—plus some unfavorable press coverage of a public relations strategy deemed less than wise.

Hoping to do better next time and to shield itself from criticism, Advanced Cell has begun hiring a team of professional ethical advisors. The move puts the company on the growing list of biotech firms now relying on outside expertise to sort out right from wrong when it comes to developing, marketing and talking about new technology. "Everywhere I turn, I see companies setting up ethics advisory boards [and] using bioethics consultants," says Arthur Caplan, director of the Center for Bioethics at the University of Pennsylvania. Caplan is one of the best-known bioethicists in the United States and tops many companies' hiring lists: He helped Pfizer decide how to market Viagra, and was recently recruited by Celera Genomics *(see "The Gene Factory," p. 64)* to counsel that company as it moves forward with plans to decode all human genes.

As advisors with little power, bioethicists could be used by some companies as mere window dressing. But Carl Feldbaum, president of the Biotechnology Industry Organization in Washington, D.C., argues that the trend is sincere and irreversible. "We have learned from the graveyard of nuclear power," says Feldbaum. "They thought the public was too ignorant to be included in the debate."

—Vicki Brower

BIOMETRICS

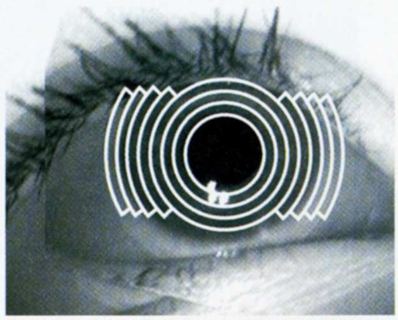
On-Sight Security

Forget your PIN and look the ATM in the eye

YOU'RE HUNCHED OVER THE keypad at the ATM, trying to remember your PIN (was it Aunt Bess' birthdate backward, or your first girlfriend's phone number?), hoping the big guy behind you can't see what you punch in. What if, instead, the machine could recognize you all by itself? That's the idea behind an iris-imaging identification system produced by Moorestown, N.J.-based Sensar now in pilot testing at ATMs and bank tellers.

Iris-based identification, proponents of the technique say, has a number of features that make it highly accurate and broadly applicable. No two irises are identical—even an individual's left and right irises are different. The tangled network of connective tissue that creates the random patterns of the iris is protected from environmental influences because it lies inside the eye. And computers can adjust for light conditions and glasses or contact lenses. Iris imaging is thus finding its way into an impressive variety of applications—from computer access control to automated fare collection on public transportation to the identification of thoroughbred horses.

Sensar, a three-year-old spinoff of the Sarnoff Corp. in Princeton, N.J., brings iris identification to the ATM by using technology adapted from Sarnoff military imaging systems to zero in on customers' eyes. "You don't have to do anything," says Rob Van Naarden, the company's vice president of marketing. "We find you in the scene and take over." In Sensar's setup, two video cameras first locate the customer's head, then an eye, and finally the pupil. A third, higher-resolution camera makes an image of the iris.



SENSAR

A circular grid acts as guide while the Sensar system measures 266 eye characteristics.

Using software licensed from Marlton, N.J.-based IriScan, the system digitally encodes the image and compares it with an image on file, typically taken when a customer opens an account.

In the first public tests of the system, begun last spring, Sensar and NCR, a Dayton, Ohio-based-based supplier of ATMs, installed iris-imaging units in ATMs at a savings and loan in Swindon, England. They also placed units at three tellers and a customer service desk as an alternative to signature-based identification. In the first seven months, approximately 1,600 volunteers tried iris identification; according to Van Naarden, there were no "false accepts" (nobody was improperly granted access to anybody else's account), and bank customers overwhelmingly preferred iris imaging to PIN or signature identification.

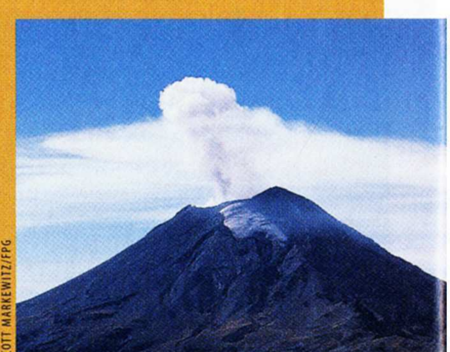
Van Naarden estimates that incorporating Sensar's identification system will add $4,000 to $5,000 to the cost of an ATM, which typically runs from $35,000 to $40,000. Sensar is conducting further pilot tests at banks in several countries; the company plans to begin full rollout of the product late this year at yet-to-be-disclosed locations.

—Rebecca Zacks

GEOCHEMISTRY

Smoke Signals from "El Popo"

Volcanologists have come a long way since Mt. Vesuvius buried Pompeii. Now they have at least a fighting chance of predicting a volcanic eruption. Yet researchers who specialize in volcanoes still don't fully understand the gaseous warning signs that spew out of active peaks. The composition of the smoke holds invaluable clues, but sampling the gases is dangerous and is often impossible as the eruption begins.



SCOTT MARKEWITZ/FPG

Recent eruptions of Popocatepetl have threatened millions of its neighbors.

To provide a safer, continuous way of analyzing volcanic gases, physicists and geochemists at Los Alamos National Laboratory in New Mexico have used a remote sensing device to monitor plumes billowing from Popocatepetl, an active volcano 70 kilometers outside of Mexico City. The concentration of one of the gases depends on the temperature within the volcano, making the device "essentially a remote thermometer," says Steven Love, a physicist at Los Alamos.

The remote thermometer is a version of a lab instrument commonly used to identify gases based on their characteristic absorption and emission of infrared radiation. By silhouetting the hot volcanic plume against the "cold" background of the sky, Love and his co-workers can measure the concentration of telltale gases formed by the volcano's complex chemistry.

The next goal is to develop an automated, continuous warning system. Love explains that if the scientists can figure out the characteristic sequence of gases emitted prior to a major eruption, it "could give us real predictive powers." Popocatepetl, like other active volcanoes, is closely monitored for seismic activity. Notes Love, "Working together with seismic monitoring, [the new technique] could certainly increase the probability of meaningful predictions."

For those living under the shadows of active volcanoes, that could mean feeling just a bit less threatened by the nearby smoking giant.

—David Rotman

FORENSIC SCIENCE

Catch as CATCH Can

A neural network helps hunt for serial killers

KING COUNTY, WASH., DETECtive Robert Keppel was hunting a serial murderer in 1974. Working from the leanest of clues, his staff assembled some 30 lists of potential suspects. One named 4,000 University of Washington classmates of a female victim. Another, every patient released from the state's mental wards in the preceding decade. Using a punch-card computer, the investigators compared the lists. Among the 25 that turned up most often was one now-infamous name: Ted Bundy.

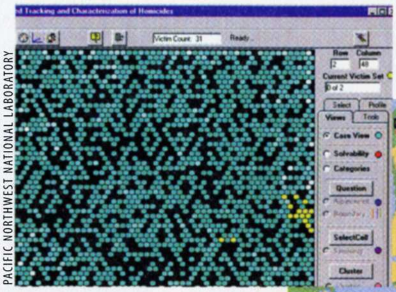
Keppel, currently chief criminal investigator with the Washington State attorney general's office, says that rudimentary program was the first ever written to catch a killer. Today, Keppel is again helping to pioneer crime-fighting computing by testing a new system developed at the Pacific Northwest National Laboratory in Richland, Wash. Called Computer Aided Tracking and Characterization of Homicides (CATCH), it uses a neural network to discover unseen patterns in the state's computerized murder-investigation records.

Finding patterns in complex data is work that humans excel at—but computers don't. Neural networks, however, process complex information much as the human brain does, says CATCH project leader Lars Kangas.

With funding from the National Institute of Justice, Kangas' team fed data on 5,500 Washington homicides—solved and unsolved—into CATCH. The program clustered similar crimes based on over 200 variables. Homicides grouped together could be the work of one person. CATCH can also generate a suspect profile by comparing unsolved cases with similar solved cases.

Keppel's crime analysts are studying the CATCH matrices to see if the neural network's hunches were right. So far, the results are mixed: two murders committed by the same person ended up on opposite sides of the matrix, but elsewhere CATCH correctly grouped known serial crimes. Though it's too soon to know if CATCH will make a decent detective, Keppel remains hopeful that the program will help finger monsters like Ted Bundy lurking in the data.

—Antonio Regalado



PACIFIC NORTHWEST NATIONAL LABORATORY

CATCH uses knowledge of a killer's *modus operandi*—such as the type of weapon used—and other crime-scene data to cluster similar cases. Washington's Green River Murders, the work of a suspected serial killer, show up as yellow points in a 2-D display (above). A map view shows crime locations as pins (right).

MANUFACTURING

Ions on the Prize

What do coin mints, sheep farmers and carmakers have in common? All depend on metal tools that wear out sooner than they would like. Although sheep farmers can just pick up a new pair of shears, the down time required to switch tools in a factory can be among the most costly components of manufacturing.

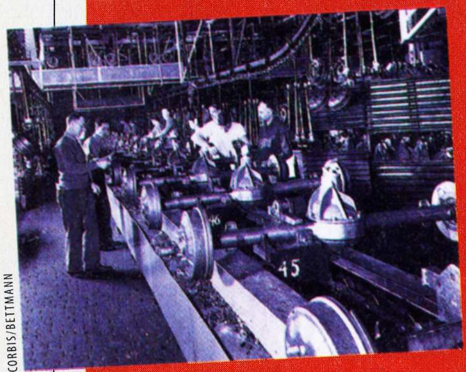
That's why a 17-member consortium led by the General Motors Research and Development Center is pushing a new materials-hardening technology—plasma-source ion implantation. The automotive industry alone hopes to realize billions of dollars' worth of savings every year, mainly from increasing the time between tool changes, says Michael Dudzik, a physicist at the Environmental Research Institute of Michigan and the general manager of the consortium. According to Dudzik, ion implantation can boost tool life from two- to tenfold.

The notion of treating surfaces with ions isn't new. But conventional methods shoot a beam of ions at the target. That method works well for flat surfaces but not for irregular parts. In the plasma approach, by contrast, the piece is placed in a vacuum chamber and zapped with thousands of volts of negative charge. Then the chamber fills with a cloud of nitrogen ions (the plasma), which bombard the charged metal surface with high energy; the ions infiltrate the outer skin of the metal, reaching nooks and crannies inaccessible to conventional ion beams, and radically augment surface hardness.

Four years after its formation, the consortium is starting to apply the technology to industrial-scale mass production.

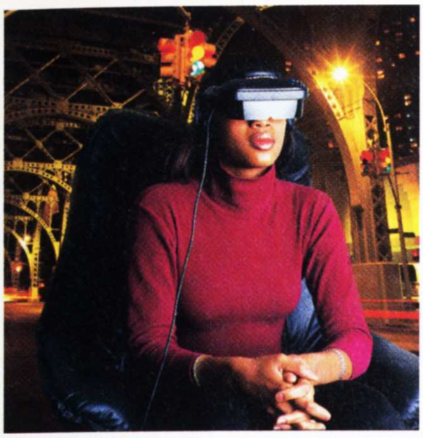
"The real need is to do this in high volumes," explains Dudzik. "That means it has to work in an assembly line setting without PhDs monitoring it. The process has to be bulletproof."

—Herb Brody



CORBIS/BETTMANN

Plasma ion implantation could help keep auto plants rolling along.



KEVIN KNIGHT

Virtual reality could help drug addicts recover and see a brighter future.

DRUG REHAB

Kick That Habit (the Virtual Way)

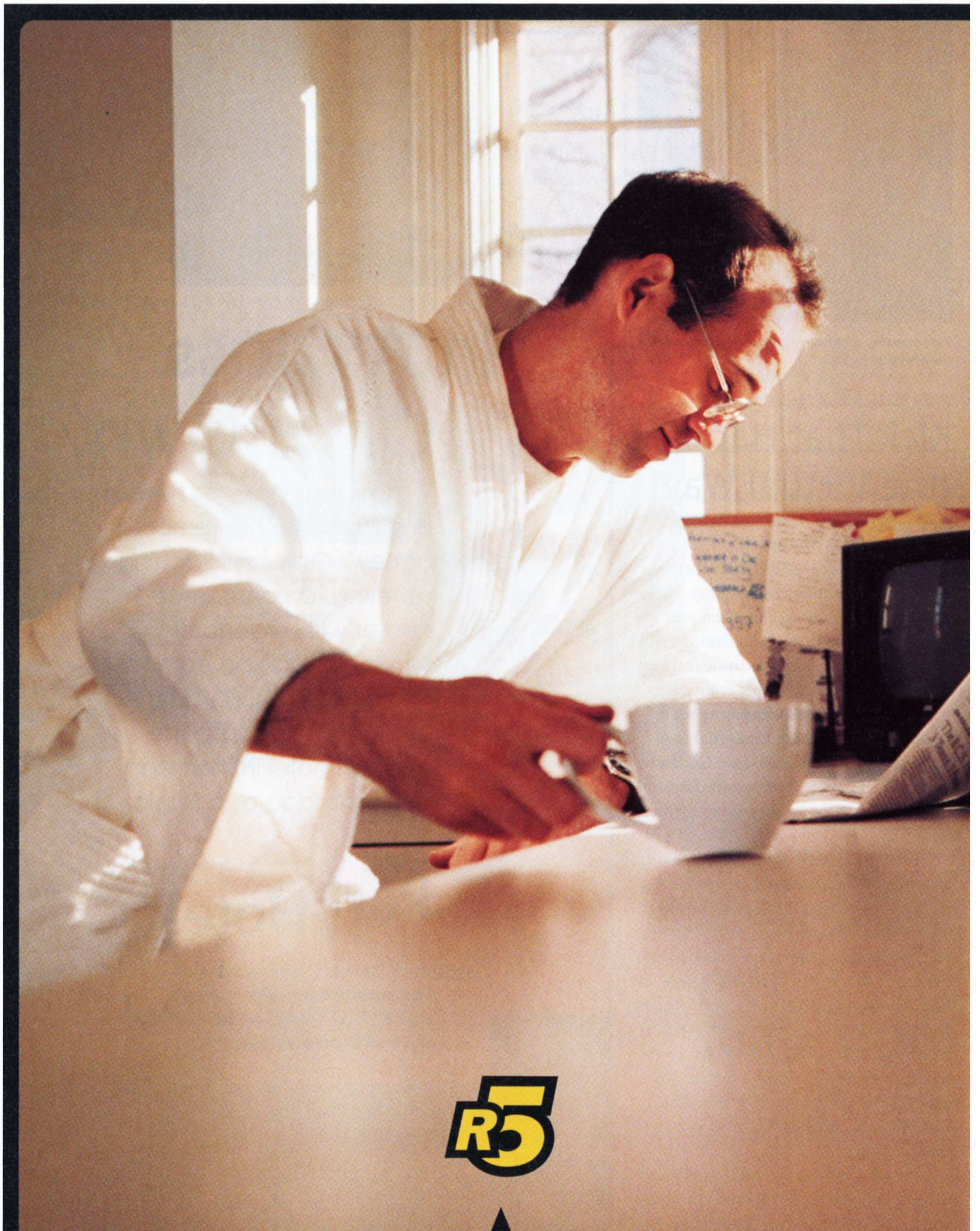
QUITTING ADDICTIVE DRUGS IS A frustrating—and often futile—process. All around the struggling addict are environmental cues that can prompt a craving for the drug. Help through this difficult experience might come from an unexpected quarter: virtual reality.

The idea is to desensitize drug users to the sights, sounds and smells that trigger the urge to get high, says Jose Gonzales, CEO of TRI Center, a for-profit chemical dependency treatment center in New York City.

Gonzales places the addict seeking treatment in an immersive virtual reality rig. While a headset displays a video from a laser disc, sensors monitor respiration rate, pulse rate, perspiration and skin temperature; therapists correlate spikes in bodily responses to particular scenes from the videodisc. Once the triggers are identified, TRI subjects its clients to the most provocative scenes over and over again. By watching the instrumentation readouts, the subjects learn to suppress their cravings.

Gonzales can, so far, offer only anecdotal evidence that TRI's technology works. But the novel approach has impressed some experts who have seen it demonstrated. "This is potentially valuable and merits further research," says Peter Berke, a social worker at Managed Health Care Systems of New York. "I applaud the attempt to do something new and different."

—**Herb Brody**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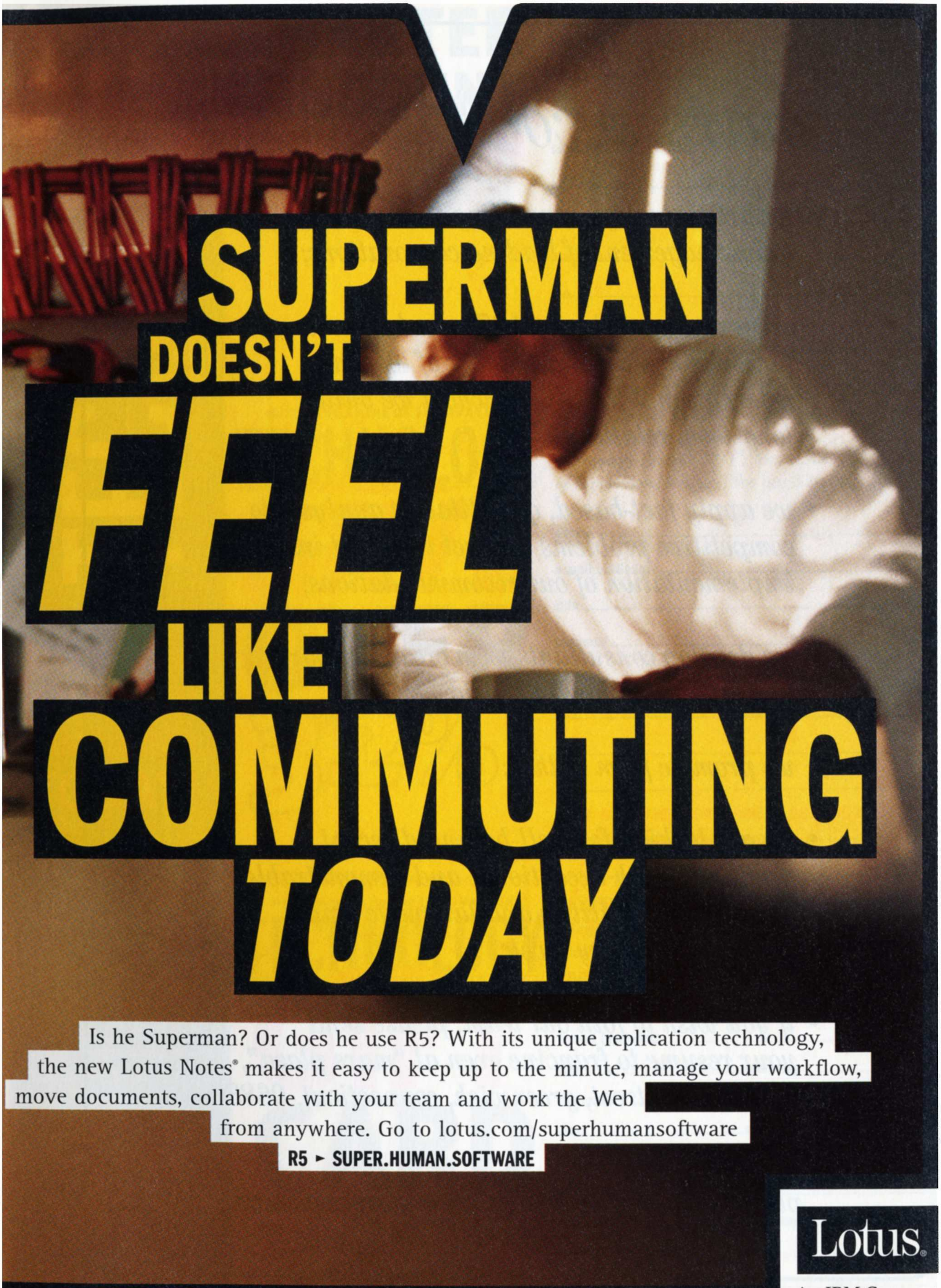
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LONDON—THERE IS A NEW NIGHTMARE SCENARIO for U.S. high-tech. And the big surprise? It doesn't involve the Japanese. That's a stunning turnaround. For decades, every self-respecting high-tech pundit predicted that, sooner or later, the Japanese would dominate the entire range of electronics industries. Japan's ability to mass-produce, to match American innovations and indeed to spawn its own knockout breakthroughs would destroy U.S. competitiveness.

But a funny thing happened on the road to Japanese high-tech hegemony. The Japanese failed to innovate, their leading companies got bogged down in capital-intensive, low-profit businesses like memory chips, and consumer electronics never took over computing but instead became victimized by over-capacity and falling prices. U.S. high-tech, meanwhile, proved more adept at miniaturization, low-cost production and continuous improvement than anyone thought possible a decade ago.

As a result, the chieftains of U.S. high-tech no longer lie awake at night worrying about the bogeyman of Nippon. Today U.S. technology companies are the envy of the world. They hold a decisive advantage over Japanese rivals in virtually every aspect of electronics.

The new threat to U.S. high-tech hegemony? High-tax, tradition-bound, regulation-heavy, antibusiness Europe!

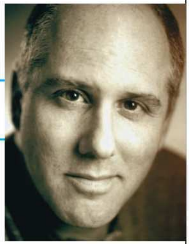
So what's the new threat? Europe. No, I'm not kidding. Having moved here myself a few months ago, I am startled to find that tradition-bound, regulation-heavy Europe, which only a few years ago was the laughingstock of high-tech, is a genuine threat. This is the same Europe whose computer companies were savaged by the advent of personal computers in the 1970s, limped through the 1980s and were virtually wiped out this decade. This is the same Europe that spawned the World Wide Web (in a Swiss physics lab, of all places) and yet allowed Netscape and a raft of U.S. upstarts to dominate the Web's commercialization. The same Europe whose high-taxes, antibusiness universities and lack of venture capital have sent thousands of innovators streaming to the United States. Yet European technology is back.

For five reasons:

■ *King Telecom.* If desktop computing—an American stronghold—has an Achilles' heel, it lies in being tethered to a physical network. Europeans hold a commanding lead over the United States in commercial wireless communications. That could be the basis for a sea change in international technology power relations. European standards are driving the industry. This raises the possibility of a European coup in systems-level computing, if wireless networks shape the computing paradigm of the next century.

■ *Birth of the New.* On the rubble of the old Europe, a new generation of high-tech leaders is rising. Consider the experience of Gemplus, France's most successful new high-tech company in a quarter-century and the world's biggest supplier of smart cards. A decade ago Marc Lassus, the founder of Gemplus, first tried to convince his then-employer, Thomson, to pursue smart cards but the French high-tech behemoth refused. Lassus bolted, and Thomson let him (legally) carry off scores of employees and valuable technology.

■ *Virtue of Surprise?* Two years ago, Andy Grove, Intel's chairman, dismissed Europe in a notorious speech delivered to the European elite at the annual World Economic Forum in Davos, Switzerland. Yet look at the way the Linux operating system snuck up on Unix and Windows, the dominant programs in technical and commercial computing. Created by a Finnish hacker, Linus Torvalds, Linux invaded the rest of the world without the backing of any big U.S. companies or even any conventional marketing *(see "Programs to the People,"* TR *January/February 1999).* Just as the Japanese once ben-



efited from being dismissed, Europeans do now.

■ *Euro Cash.* The advent of the Euro, a single currency for 11 European nations, symbolizes the cohesiveness of a region rivalling North America in size and wealth. Significant national differences remain, especially in taxation and support for higher education and research. But in business technology, English is the lingua franca and one set of standards reigns from Madrid to Warsaw.

■ *Gadget Passion.* Europe's quarter-century of hostility toward new technologies is ending. As in America, technology is now perceived as a measure of individuality and a lever of personal empowerment. For Europe's smaller nations, the marriage of the Internet and wireless communications levels the playing field with the big boys. At the margins of Europe, the passion for technology is extraordinary. The Finns have a higher rate of Internet usage than the United States.

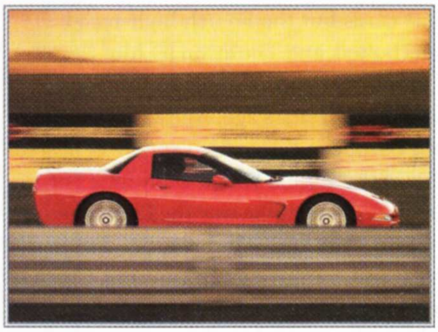
To be sure, innovators still raise hackles in Europe. And while Europe's engineering talent is surprisingly deep and its universities are starting to overcome centuries of hostility toward commercial activities, European companies still hardly rely on the Indian and Chinese diasporas, whose members make seminal contributions to U.S. high-tech companies. Finally, the top U.S. companies are adept at absorbing and coopting European talent. Still, the lords of U.S. high-tech are watching Europe. Today all technological leads are temporary. Paranoia defines high-tech innovators. Right now, Europe inspires paranoia. It should. ◊

{After 32 years, a tru

In the quest for high performance, som

By John Cafaro, Chie

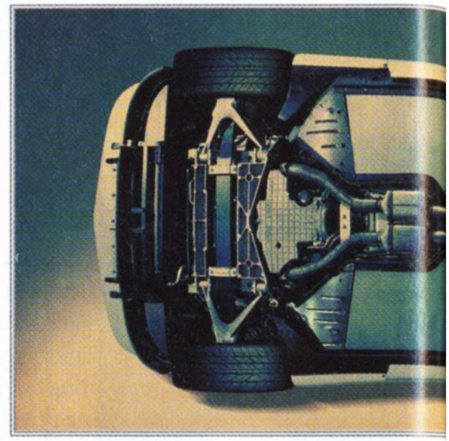
If you're an automotive designer, there isn't a more challenging or, ultimately, a more rewarding assignment than to be given the opportunity



{ The lighter, stiffer hardtop takes Corvette performance capabilities to the ultimate degree. }

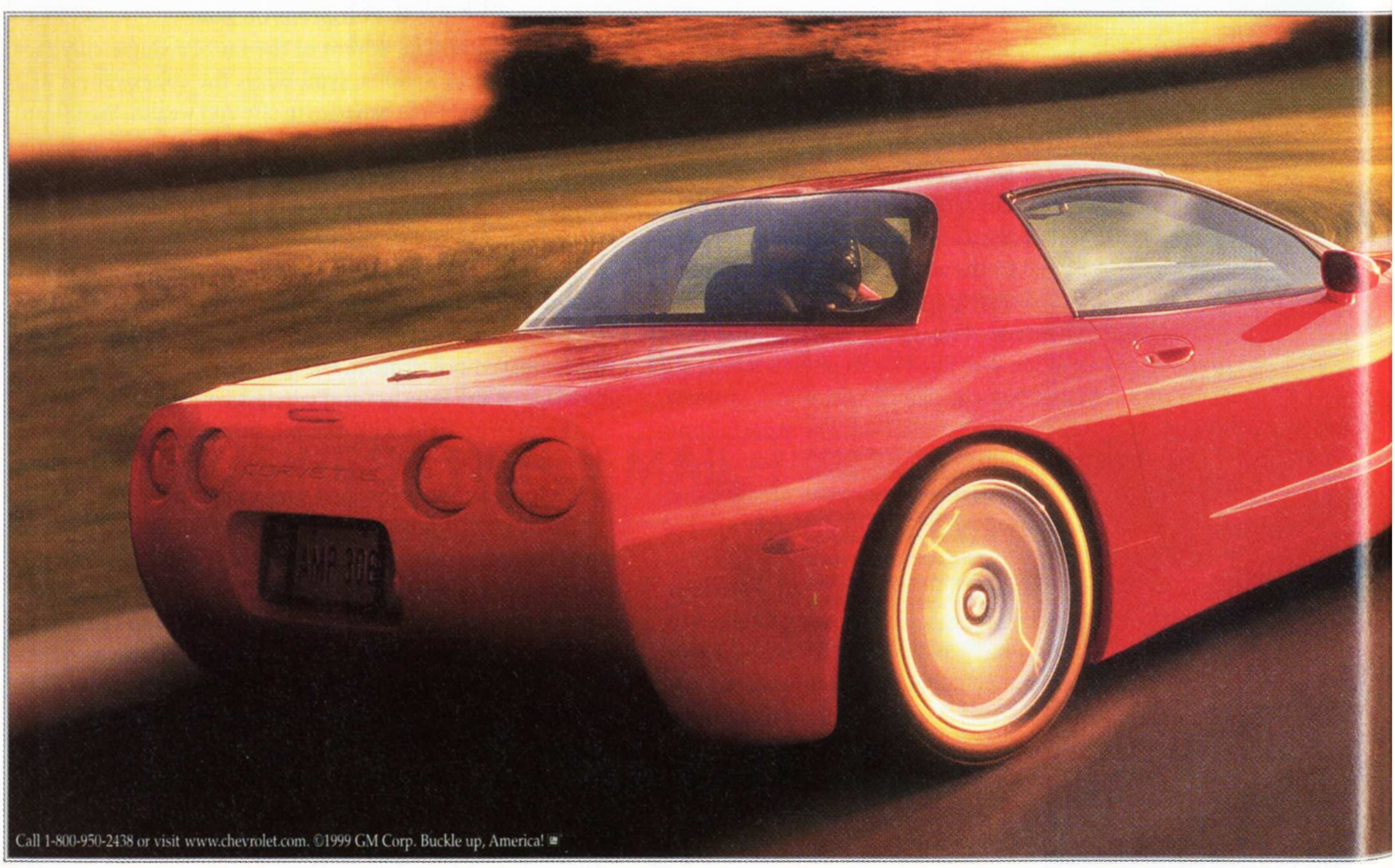
to create the next Corvette.® It's not something we take lightly. Great automotive design and Corvette have gone together since the very first one in 1953. It's about heritage, passion, tradition and the future, all at once. And the fact that any new Corvette design must speak loudly of the performance potential that lies underneath the skin. The Corvette hardtop certainly had to measure up to some pretty lofty standards.

Our Future Must Start With Our Past. Our past is really important to the Corvette Design Team. Each and every day, we live and breathe Corvette history. Legends like the Corvette SS. The original Sting Ray. The '63 Coupe. The Mako Shark. It's all there for us to see whenever we turn a corner in the halls of our design studios. From memorable street cars and significant race cars to forward-looking concept cars and design studies, we feel the



{ Detailed aerodynamics: Like all Corvette models, the hardto

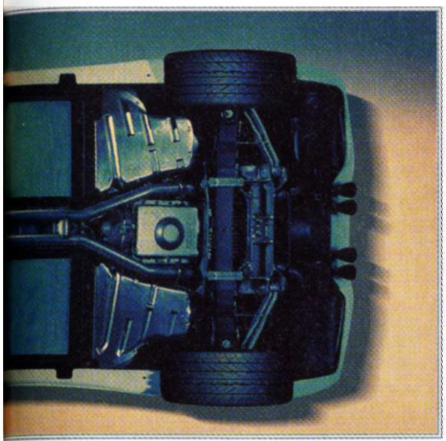
presence of every Corvette that ever came before. Which is exactly why it's such a privilege to have the opportunity to design the next one. Because as designers, we don't just create a new Corvette, we get a chance to make history.



ardtop Corvette is back.}

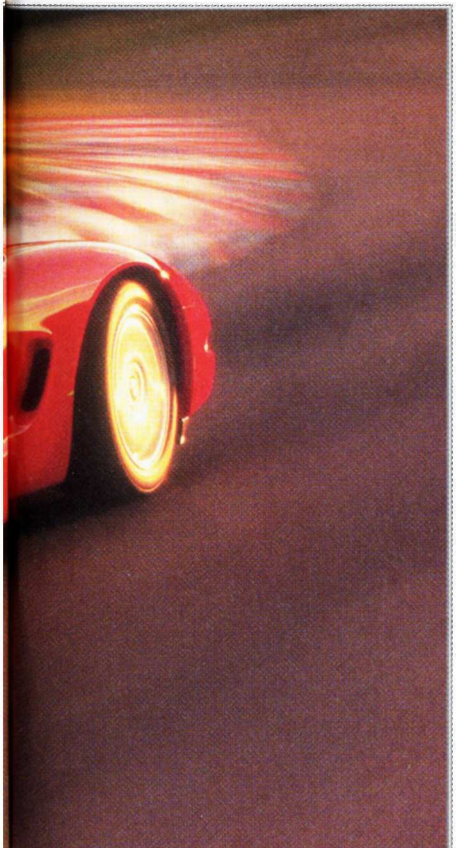
imes you have to get back to the basics.

esigner, Corvette



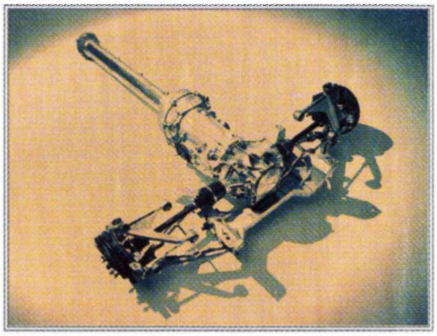
dercarriage is designed to manage air flow and reduce drag.

The Hardtop Is the Essence of Corvette. Since the era of the competition Grand Sport, a fixed-roof configuration has always meant the ultimate performance Corvette, and the hardtop is no exception. To accentuate the



purity of the shape, we created a minimal "greenhouse," getting back to the functional simplicity of all sports cars. By doing this, we enhanced the taut, muscular fenders, elegant wheel openings and aggressive wheels. We feel the look emphasizes the true spirit of the car. The net impact we were going for is one of no-nonsense power and pure performance; in other words, the very essence of what Corvette is all about.

For Purists, It's the Ultimate Corvette. We didn't want this Corvette to lack for anything. After all, this was the first fixed-roof Corvette in 32 years, so it had to have all the performance ingredients that make the convertible and coupe so special to begin with. The Corvette Design Team went to work from there. Starting with its lighter-weight structure consisting of a strong perimeter frame combined with a center backbone (the C5 was already over four times stiffer than the previous generation), the hardtop configuration is even more rigid for enhanced road "feel" and overall solidity. From there, this Corvette gets all the right stuff: all-aluminum 5.7-liter V8 with sequential-port fuel-injection, 345 horsepower at 5600 rpm, 350 lb.-ft. of torque at 4400 rpm and electronic "drive-by-wire" throttle control. Close-ratio six-speed, rear-mounted manual transmission. Limited slip differential. Speed-sensitive, variable-effort, rack-and-pinion power steering. Huge 4-wheel, ventilated power disc brakes. 17"x 8.5" aluminum wheels in the front, 18"x 9.5" in the rear with Goodyear Eagle F1 GS high-performance, extended-mobility tires. Lightweight aluminum suspension pieces and standard Z51 Performance Handling Package (which includes stiffer springs, larger stabilizers and larger mono tube shocks). In short, there's enough performance hardware here to please



{ The rear-mounted transmission in Corvette contributes to the excellent weight distribution and responsive performance. }

even the most hard-core enthusiasts. And that's what it's all about, really. Performance for performance sake. For purists, it is easy to see why the hardtop is the ultimate Corvette.

Work? It's a Labor of Love. To say everyone here on the Corvette Design Team loves these cars is an understatement. We drive them. We collect them. We even race them. We're Corvette enthusiasts through and through. That's why we love the hardtop. It represents everything Corvette stands for: Power. Passion. Advanced Technology. Performance. And The Future. Drive one and you'll see what we mean.

The Only Sports Car
That Matters.

CORVETTE

High-resolution satellite images are about to flood the marketplace. They could be good for business, but what will they do for terrorists?

God's Eyes for Sale

BY IVAN AMATO

The idea that led to John Hoffman's breakthrough came from an unlikely place: a government bureaucrat. Hoffman had been thinking of ways to incorporate high-quality satellite data—the kind that intelligence agencies use—into his fledgling aerial photography business. The problem was that the sort of data the United States has is mostly on places like Siberian oil fields. Not much commercial potential there. But the government official's remark turned the whole thing around. "He said to me," Hoffman recalls, "'You know son, what you ought to do is to go up to the blankety-blank Russians, because by God they've been taking pictures of us for 20 years.'"

That advice led Hoffman to experiences reminiscent of a Tom Clancy novel. With the aid of Mike Laserson, who had helped broker U.S.-Soviet grain deals in the 1970s and 1980s, Hoffman finagled a meeting with the Russian Ministry of Defense in late 1994 to promote his idea of putting spy-quality satellite images on the commercial market. Things didn't start off too well, Hoffman recollects: "Here were a couple of Americans walking into the Russian intelligence community and saying, 'Hey, you have all these neat photographs. We want you to declassify them so we can sell them to people.'"

PHOTO-ILLUSTRATION BY MARK TUCKER

But after a few days of discussion followed by a vodka-soaked dinner at the OMNI hotel in Moscow, Hoffman and Laserson won over the Russians. Which made it possible to form a joint venture between Hoffman's company, Aerial Images, Laserson's one-man consulting firm, Central Trading Systems, and Sovinformsputnik, the government spinoff that promotes and markets products and services of the Russian Space Age. After a first failure, a SPIN-2 satellite launched by the joint venture succeeded, spending 45 days in late 1997 snapping thousands of pictures. Then Microsoft, Compaq and Kodak pooled their skills to create a Web-based catalogue and fulfillment service called the Terraserver, which they touted, byte for byte, as the largest database on the Internet.

With 2-meter satellite images (which resolve objects as small as 2 meters across) on sale last summer for as little as $10 each, Hoffman and his partners won an early leg of a now highly competitive race to cash in on data that were once the province of the spooks. "The intelligence community had a 30-year monopoly on high-quality satellite imagery," says Marty Faga, former head of the formerly classified National Reconnaissance Office, which has been responsible for U.S. spy satellites since 1962. "The monopoly is over."

In fact, that monopoly is over with a vengeance. In the next months and years a gaggle of companies around the world plan to launch high-resolution imagery satellites, some capable of achieving resolutions fine enough to detect objects less than a meter across—which used to be state of the art for the intelligence community. According to projections by some industry analysts, sales of this new commodity, along with value-added services, such as merging satellite imagery with geographic land-use data, could reach half a billion dollars within a few years. Companies could use the spy-quality data to see what their competitors are doing. It might help foresters to inventory trees by species. News outlets could use it to identify breaking stories. Urban planners could see how cities grow and where to put streets or highways.

Imagine keeping track of your competitors, watching out for fires, searching for oil, or peering over a neighbor's fence—all from above.

That's the upside of this explosion of once-super-secret information. But looked at from another perspective, a darker image appears. What if, for example, Saddam Hussein had access to 1-meter spy-satellite data during the Gulf War? Might his troops have put up a tougher fight? What if some other rogue state or terrorist groups could use the satellite to target nuclear-tipped missiles on major international airports? According to John Logsdon, director of the Space Policy Institute at George Washington University, there are plenty of terrorists, industrial spies, rogue governments and other miscreants waiting to get their hands on such data.

The problem, says Logsdon, is that this information is poised to spill into the marketplace so fast that policy-making hasn't had a chance to catch up. This is an area, he says, where "capability may be running ahead of a thoughtful, comprehensive assessment of the pros and cons of going forward." The Clinton administration's policy goal to (in the words of an administration official who insisted on anonymity) "strike a balance between foreign policy and commercial interest" has put things on the fast track; the Department of Commerce's process for licensing purveyors of high-quality satellite data is a fairly business-friendly one. And with foreign competitors in Canada, France, India, the former Soviet Union, Japan and Israel, the data are likely to become available to just about anybody, anywhere in the world.

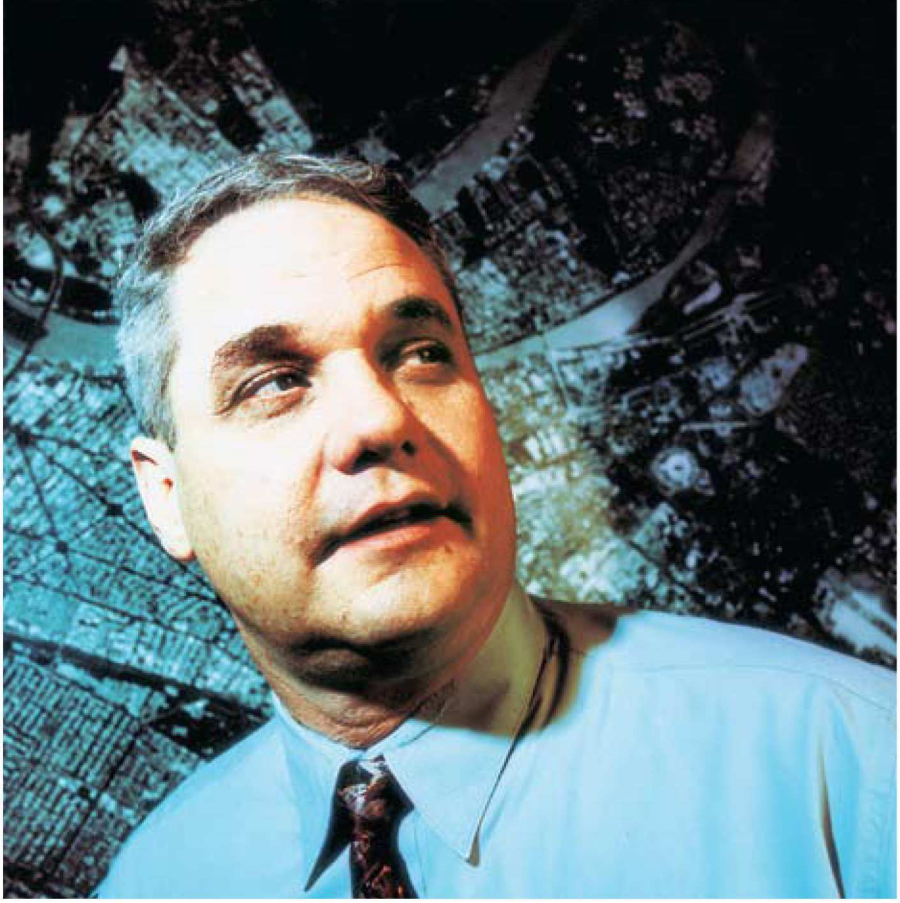
Before figuring out the consequences of this situation, it's a good idea to take a step back and look at how we got into it. Anybody who watches the weather on TV knows that low-resolution satellite imagery has been publicly available for many years. NASA started peddling low-resolution pictures from the Landsat program as early as the 1970s. Since then, selling low-to-moderate-resolution data (down to the 10-meter range) has become a globally competitive industry, with government-run or -assisted agencies from the United States, France, India, Russia, Europe, Japan and Canada all in the game.

But that kind of imagery is a very different proposition from the kind of high-resolution imagery that is about to flood the market. And it took a couple of recent developments to get the high-resolution business off the ground, as it were. For one thing, spacecraft and launches got a whole lot cheaper. "It's now possible to get into the business for $20 million to $50 million," says Ray Williamson, a colleague of Logsdon's at the Space Policy Institute. The Russians can put your goods into space at rock-bottom prices from their Baikanur launching facility in Kazakhstan. China also provides budget launch services.

The market for satellite imagery also has been growing and diversifying over the past few decades. Many early users were shallow-pocketed scientists tracking large-scale phenomena such as weather, forest decline, ocean conditions and global warming. But that kind of market couldn't support a whole private-sector industry, so governments provided big-time subsidies to keep the satellites in orbit. In the meantime, though, a large new commercial sector emerged: the Geographic Information Services (GIS) industry.

GIS companies work primarily with corporate customers, offering them overhead data relevant to their businesses. The walls of GIS companies are papered with satellite images from Landsat, France's Spot Image, Canada's RADARSAT (which gathers remote sensing data using high-resolution radar rather than optical technology) and other providers. Analysts combine these images with geographic information, such as jurisdictional boundary maps, agricultural resources and demographic data. The growth of GIS provided a basis for "incorporating all kinds of interesting information into satellite images," says Williamson. With these value-added service providers now in place, high-resolution spy-quality images now have a sizable market in waiting.

As soon as the conditions were right, people like John Hoffman were ready to step forward. In fact, high-resolution imagery was part of Hoffman's planning from the time he founded Aerial Images in Raleigh, N.C., in 1988. But it wasn't until after the Cold War and his adventures in Moscow that he was ready to get into orbit. By May 1996, a Russian Cosmos spacecraft bearing a SPIN-2



CHARLES HARRIS/STONE SOUP PRODUCTIONS

Looking over his shoulder: John Hoffman's company, Aerial Images, has plenty of competitors.

What is going to be done with all this new, high-quality imagery when it hits the market? With these images, you could monitor forest fires or search for oil and minerals, which are the kinds of jobs commercial satellites have traditionally been called on for. Or you could use them for something completely new, such as getting a row-by-row assessment of the water needs of your soybean crop. If you're a realtor, you could show your customers several prospective neighborhoods—from above.

If you're in law enforcement, you might use satellite imagery to monitor suspected bad-guy hangouts. If you're nosy enough, you conceivably could buy a view over your next-door neighbor's fence, too. More likely this will mean your business competitor's fence. "Imagine easily keeping track of your competitor's efforts to install its communication network," writes former CIA analyst Fred Wergeles in *Competitive Intelligence Magazine*. "Imagine being able to determine the energy output of your competitor's power plant." Wergeles, a senior consultant with the Futures Group in Glastonbury, Conn., says the new era of spy-quality satellite data will turn these notions into reality. Using satellites with infrared sensors that can measure the amount of heat coming from factories, for example, executives of automobile manufacturers and chip makers, among others, will be able to get better estimates of their competitors' production. Wergeles believes that satellite imagery will become part of the growing arena of competitive intelligence in which companies try to wrench market share from rivals by gathering previously unavailable information.

John Hoffman has lots of other ideas for his product, which he describes in an almost breathless fashion. The new imagery will be valuable "for the small business user who wants to create a delivery map, or the consumer who wants an image of their neighborhood or where they work, or of the family homestead." Travelers might benefit, too, he says: "You're going camping in Yellowstone and you want to carry an image with you...or you're going to Paris and you want to see what Paris looks like ahead of time, to be able to see the way the streets are laid out. An image is frequently more informative than just a line map."

Hoffman's upbeat attitude stems partly from the advantages he thinks working with satellite images holds over the traditional methods of making and selling aerial imagery, which he's followed in his own business for years. The traditional approach is laborious, time-consuming and expensive—akin to the wedding-picture industry: Photos are taken from airplanes, helicopters and balloons, developed, turned into proofs for customer selection, printed and delivered. Since satellites can image so much more territory from their lofty perches, Hoffman expects them to be a more cost-effective source of overhead data. What's more, because the images usually start out in digital form (except, of course, Hoffman's own SPIN-2 imagery), they are easier to store, manipulate, process, download, upload and print than their film counterparts.

The new spy-quality images won't just be cheaper and more

satellite with a high-resolution camera earmarked for his joint venture was perched atop a Soyuz B rocket at the Baikanur site.

These Russian "birds," as satellites are known in the trade, carry sophisticated optical systems but they aren't up-to-date in every respect. Most of Hoffman's competitors beam images back to earth via telemetry systems. But the Russian SPIN-2s carry film that must be physically retrieved from a canister that falls back to earth. The film is processed in Russia, then sent to the United States, where precision scanners convert the photographs into digital images. Once digitized, the imagery data can make it onto disks, databases for GIS providers, the Internet and the rest of the digital world.

Launching satellites of any kind isn't a business for the queasy; failure is often part of the game. The first SPIN-2 had equipment trouble and never made it into orbit. But Hoffman has a strong stomach, and the second try, in 1997, succeeded, providing the images for the Terraserver, offering the general public its first taste of what only intelligence types used to be able to see.

That taste soon will be followed by a veritable banquet of high-resolution images, as Hoffman's competitors get into the business *(see "The Image Makers" on p. 40)*. In the next months and years several companies, including Space Imaging of Thornton, Colo., Orbital Sciences of Dulles, Va., and Earth Watch of Longmont, Colo., expect to launch high-resolution imagery satellites. Some will offer resolution slightly finer than 1 meter—better than Hoffman's SPIN-2 birds can now produce. And although that's getting closer to the capabilities of the actual spy satellites, the real spooks say they still have the sharpest-sighted birds in the sky. "We will remain a step ahead of commercial capability," says Rick Oborn, spokesman for the National Reconnaissance Office, whose satellites these days can reportedly achieve a resolution of 10 centimeters.

The Image Makers

Two of the first companies into the new market for high-resolution satellite imagery are John Hoffman and his SPIN-2 venture Aerial Images and Space Imaging of Thornton, Colo. Space Imaging plans for its IKONOS-1 satellite—a scheduled late-1998 launch of which was postponed at least until this spring—to be the first bird to supply 1-meter imagery to the commercial market.

But those two players will face some competition. Earth Watch of Longmont, Colo., is looking to capture as much of the market as it can. The technical foundation for the company was an unexpected byproduct of Ronald Reagan's Star Wars program. Scientists, including Walter Scott at Lawrence Livermore National Laboratory in New Mexico, were developing small, inexpensive satellites to detect, track and then kill incoming ballistic missiles. Scott realized that such "smallsats" could have commercial uses. He teamed with Doug Gerull, who was then executive vice president of Intergraph, a Geographic Information Systems (GIS) company. They founded World-View and set up shop in Colorado. Their goal was to become the first company to market 3-meter resolution by 1996 or 1997 and then to follow that feat with imagery of 1-meter resolution.

Things looked promising at first. The company was the first to receive a license from the Department of Commerce to privately operate high-resolution remote-sensing satellites. But its first satellite, EarlyBird, failed to reach a useful orbit after a Russian rocket lofted it into space. The failure forced the company to downsize and reorganize (changing its name to Earth Watch in the process). Now Earth Watch is banking on a 1999 launch of its 1-meter-resolution QuickBird satellite to keep it in the game.

Another competitor is Orbimage, the subsidiary of Dulles, Va.-based Orbital Sciences, which pioneered the use of Pegasus rockets launched from jets to get payloads into space. Orbimage already has two lower-resolution satellites in orbit—OrbView 1 and 2. Orb-View 3, which is scheduled for launch in mid-1999, and OrbView 4, which should go up in early 2000, are now under construction in a facility in Germantown, Md. Both will have resolutions of 1 meter for black-and-white images and 4 meters for multispectral images. In addition, OrbView 4 will offer advanced "hyperspectral imagery" providing customers with 280 data-packed spectral bands.

"It will be the only satellite in the world that can supply that kind of information," at least commercially, says Gil Rye, president of Orbimage. With data from so many different parts of the electromagnetic spectrum, customers like the Air Force will be able to see through camouflage, says Rye.

Like most of the other domestic and foreign high-resolution commercial imagery satellites approaching their launch dates, Orbimage's birds will capture images digitally using electronic detectors called charge couple devices. This data then will be relayed to ground stations and from there into the ever-more-powerful nexus of information-handling technologies. If a customer is willing to pay for its own receiving station, "we can downlink images real-time," says Rye.

Who needs such service? You guessed. "Our markets are: U.S. national security and foreign national security," says Rye, a 1985 retiree from the Air Force who also was director of the Space and Intelligence Program of the National Security Council in the Reagan administration. Besides the security markets on the top of Rye's list, he says, his company also expects to capture some of the scientific and environmental monitoring markets.

convenient than the old ones. "With the increase in spatial details comes the ability to not only map geological features, but to ask questions that you could not answer with lower-resolution imagery," says geologist John Amos, an analyst with Advanced Resources International, a GIS firm in Fairfax, Va.

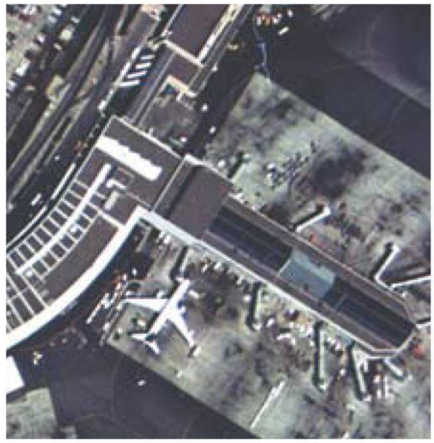
Lately, Amos has been spending lots of time helping clients identify "sweet spots" in beds of sandstone suspected of harboring natural gas. Most of the gas is locked in low-permeability sandstone. The sweet spots have higher permeability, making it easier to get the gas out. Amos' geologically trained eyes can garner subtle hints from satellite imagery about where those spots might be. When the higher-resolution imagery becomes available, he'll be able to zoom in on candidate sweet spots first pegged during analysis with the lower-resolution imagery. And that could make it easier to rule out the pseudo-sweet spots that would soak up money while producing no gas.

Still, Amos expects that the technophilic urge of clients for the hottest new gadget will be something to guard against. The irony of high-resolution imagery, he explains, is that "you can actually lose the forest for the trees." These images offer more detail, but over much less area than low-resolution images. "There will always be a value in looking at large enough areas at low resolution so that the brain doesn't get swamped with details," Amos says.

And though the high-resolution data could help people like Amos, who spend their time looking at huge sweeps of ocean and sparsely developed countryside, it might be even more helpful to those concentrating on urban areas. One of the first to log on to the Terraserver was Eli Naor, an architect with VBN Associates in Oakland, Calif., designing a roadway and bridge connecting a freeway to the Oakland Airport. Says Naor: "I was able to locate the Bay on a graphic map of the world and then through a series of enlargements I was able to zoom in on the Oakland Airport at a high degree of magnification, find the roadway in question, and acquire the image." He says overhead perspectives are good for business because they help him do his design work as well as show it in presentations. Naor says he's also excited about helping his kids use the newly available satellite imagery for school projects.

THE IMAGE OF AN ARCHITECT-DAD HELPING HIS KIDS do their schoolwork represents the soft and fuzzy side of the newly available pictures. But the prospect of North Korea aiming nuclear missiles is a different matter. It's that kind of scenario that has made the high-resolution imagery business a topic of debate among Washington lawmakers and regulators. And indeed, the new satellites could even erode personal privacy. If you suspected your neighbors were building a swimming pool on the other side of a high fence, you might be able to confirm your hunch with some satellite data (though at 1-meter resolution, would-be Peeping Toms are bound to be disappointed by the poor detail of the view from space).

A newly formed Remote Sensing Interagency Working Group hopes to steer the emerging industry in a direction compatible with national interests. The group, including representatives from the Departments of Commerce, Defense and State, has been developing guidelines for incorporating safeguards into the licenses for selling high-resolution satellite imagery. Satellite operators must keep a log of all pictures their satellites take. They must close their cameras' shutters when the government deems that dissemination of high-resolution satellite imagery could threaten security. There are also



SPACE IMAGING

Zooming in: 25-meter and 5-meter images, such as those of the San Francisco Airport shown at the left and center above, are available from existing satellite sources (in this case, the U.S. Landsat and the Indian Remote Sensing satellite respectively). Space Imaging and others are planning to launch into orbit new "birds" capable of capturing 1-meter images like the one on the right, simulated using aerial photography.

idiosyncratic limitations, most notably the prohibition of any U.S. company gathering imagery over Israeli territory that is finer than imagery available from non-U.S. companies; Space Imaging, for example, will not be able to sell 1-meter pictures of Israeli territory from its yet-to-be-launched IKONOS-1 satellite until some other country offers the same product. (This was a concession to Israel, whose lobbyists, some say, pushed for it on security grounds.) And a 1997 article in *The New York Times* reported that the Pentagon was preparing the ultimate defense: anti-satellite weapons capable of destroying the imagery satellites.

Where the balance of good and evil wrought by the new view will fall depends on whether the information increases or decreases security in the world. Without question, many of the first customers in the new market will be national governments. "Space imagery is going to be part of the intelligence trade for the other 190 countries that haven't had access to it," says John Pike of the Federation of American Scientists in Washington, D.C., where he monitors the intelligence community. "By helping countries know what is going on around them, this could be a tool for the countries of the world in either planning security-threatening actions or security-stabilizing actions," says Logsdon of the Space Policy Institute. "Here is information that heretofore has not been available and can be used for both positive and negative purposes."

In one of the more alarming scenarios, ill-meaning, technology-savvy terrorists or governments might try to couple high-resolution satellite imagery with the already commercial Global Positioning System (GPS). The GPS is a multi-satellite system by which the position of anyone or anything can be determined with an accuracy of tens of feet in the case of commercial uses and better in the case of military ones. "The real concern," says the Space Policy Institute's Williamson, "is that with this high-resolution data and a couple of GPS receivers, you can do very good targeting."

Pike points out another possible unintended consequence that high-resolution satellite imagery could catalyze. Countries like Argentina and Brazil have to take a certain laissez-faire attitude about each other's military power at the moment because they have no easy way of answering the question: What is my neighbor's level of military readiness? With high-resolution satellite imagery, however, "it can be an answerable question," says Pike. So lots of information that used to be out of mind because it was out of sight can now come into view. And that could mean military commanders and decision-makers may feel compelled to cover themselves or impress their superiors by gathering imagery intelligence they never used to have access to.

Most of the expert observers contacted for this article believe that, on balance, it's better for adversaries to know more rather than less about each other. "By and large transparency is stabilizing," says Chris Simpson, a former journalist who now teaches at American University, where his research focuses on national security issues in communications. Simpson points to the Dayton Accords that were signed following meetings in 1995 when opposing leaders in the former Yugoslavia finally met at the Wright-Patterson Air Force Base in Ohio to try to end the bloodshed. The negotiations included "fly-by" satellite imagery that provided a pilot's-eye view of a region. "They systematically tracked where various forces were, what the geometry of the forces was, what towns were run by what groups," says Simpson. "It captured their attention enough that they were able to come to a cease-fire." But Simpson is no Pollyanna: "Circumstances in which satellite data might not be stabilizing are ones in which two sides are evenly matched, but where one side has a greater amount of information than the other." India and Pakistan, who are threatening to play out their own Cold War, come to mind.

And lying beyond questions of security—personal, corporate, national and international—is the issue of how the new pictures will affect our experience of the world. The images won't tell us just where the weather is, but also "where urban development is taking place, where highways will be, where environmental crises are centered and where they are not centered," says Simpson. "The next generation will grow up with this kind of overview as an integral part of the conceptualizing of the world in the same way that people have grown up with TV as an integral part of their lives."

There is a big difference, however, between TV pictures and those that are about to flood us with fire-hose strength. Most TV imagery is local and all-too-human: couples in their apartments, players on a baseball field, cops in their cruisers. Satellite imagery is a veritable "God's-eye view" of this world, though the raw images are nonparochial. Political boundaries don't show up; the local is seamlessly connected to the global. The arrival of spy-grade satellite data into everyday life stands a chance of countering TV's small pictures with the big picture. It could provide yet another tool, pixel by pixel, for human beings to express their ill will. Or, if we're lucky, that big picture could have great healing power. ◊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Nanotechnology: The Hope & The Hype

Everywhere you look, technology is making things smaller, from cell phones that you can stuff in a pocket to PCs with power that only a few years ago would have required a supercomputer. The key to all this diminution is the shrinking of microelectronics. Indeed, if you were to disassemble a laptop computer, you would find at its heart, carefully laid out on a chip, roughly 4 million tiny transistors, whose carved silicon features have been whittled down to the scale of several hundred nanometers across. A nanometer is a billionth of a meter—about the size of two large atoms—and a hundred of them are still only about the size of a virus.

On the scale of daily life, that is almost unimaginably small. But if electronic devices are going to continue to shrink, getting cheaper and faster, it's not small enough. To maintain the current rate of growth in computing power, microelectronics makers will have to squeeze roughly 18 million transistors on a microprocessor chip by 2003. That means feature sizes will need to be as small as 130 nanometers. This, then, is where you begin to enter the nanoworld and existing technologies begin to fall apart.

Anticipating the importance of this mysterious region, chemists, materials scientists and physicists are exploring the very small scale: the world where individual atoms and molecules rule. In recent years they have, for the first time, put together rudimentary devices that measure only a few nanometers. Building at this tiny scale is called nanotechnology, and if researchers can learn to do it well, nanotech could provide ways to squeeze not just millions but billions of transistors onto each chip. And the implications go far beyond electronics. Working at the molecular level could lead to huge advances in optical communications and photonics, as well as ways to probe individual cells.

But if the potential for this new nanoworld is, so to speak, immense, so is the hype. Since this domain remains largely uncharted, it has become a rich territory for speculation. In the imagination of some nanoaficionados, future nanorobots (known as assemblers) will shove molecules together, working in mini-factories that can build just about anything from the most basic raw materials. Nanosubmarines will cruise the circulatory system, stopping occasionally to repair a cell or tissue.

These speculations may sound like the plot of a campy sci-fi movie, but they're not. They come primarily from the imagination of K. Eric Drexler, who popularized the notion of molecular manufacturing in 1986 in his book *Engines of Creation.* Drexler, who holds a PhD from MIT in molecular nanotechnology, founded the Palo Alto, Calif.-based Foresight Institute in 1986 to promote his ideas. And since then, this vision of nanotech has captured the imagination of a loyal band of enthusiasts, many of them skilled computer scientists capable of making nanomusings come alive on the electronic screen.

These concepts can be shrugged off as excesses that have done little damage and in fact may have helped fuel public interest in nanotech. Many leading researchers in the field take an indifferent attitude toward these hyperbolic statements, simply pointing out that there is no experimental evidence that such things are possible. But some experts argue that these nanofantasies have taken on a misleading momentum of their own, hijacking the public's fledgling perception of the nanoworld.

Soon enough, though, the hype will be sorted from reality in the field, because researchers in many labs around the world are beginning to do the real work, with real materials, that will show what is—and what is not—possible on the nanoscale.

Turn the page for a set of stories that separate hype from hope as we move toward this very small world.

Will the Real Nanotech Please Stand Up?

After decades of visionary speculation, a raft of new research—along with the first rudimentary devices—have begun to define the outlines of the nanoworld.

BY DAVID ROTMAN
PHOTOGRAPHS BY ANNE HAMERSKY

THE GRAND BALLROOM OF THE BOSTON Marriott had been packed with a standing-room-only crowd of several thousand materials scientists eager to hear Richard Smalley's evening plenary talk on "new devices and materials from carbon." Afterward, in a nearly empty meeting room at the hotel, the Rice University chemist looks tired and spent as he fields questions. Then suddenly he's revitalized; he leans forward and focuses intently. The conversation has swung to one of his favorite subjects: how nanotechnology will help save the world.

There are roughly 6 billion people on Earth, Smalley points out on this November night, and research aimed at producing better, cheaper, more efficient materials will be one key to feeding and housing that population as it soars toward an eventual steady state of 10 billion or more. But the limits to how strong, conductive and intricate a material can be "are set at the nanometer scale," he says. "The dream," says Smalley, "is to build with that level of finesse, to make it perfect down to the last atom." This capability, he contends, would bring smaller, more efficient batteries, stronger materials, and vastly improved and cheaper electronics.

These are no ravings from the latest trendy "futurist." Smalley is one of the country's most respected chemists, a 1996 Nobel laureate in chemistry, and director of a new $33 million Nanoscale Science and Technology Center at Rice. Nor is he alone. A growing number of researchers share Smalley's conviction that controlling the structure of materials down to a few atoms or molecules will have an immense impact on everything from computing to medicine. The ability to manipulate matter an atom at a time has been the stuff of science fiction for years. But recent development of high-tech tools, especially probes sensitive enough to both image and move individual atoms and molecules, has begun to turn these fantasies into scientific reality.

During this past year, two groups of researchers have independently fabricated a transistor out of a single carbon molecule. Scientists have built prototype information storage devices with data bits as small as 50 nanometers across. Other researchers have recently made a molecule that rotates, acting as a nanowheel, as well as a rudimentary abacus with single molecules acting as the sliding beads.

These are, admittedly, laboratory novelties. And, in truth, no one really knows what will result from the emerging science. For one thing, while scientists can painstakingly make nanodevices one at a time in the lab, they still must find a rapid—and

Solitary molecules: IBM's Phaedon Avouris is focused on making tiny objects out of individual carbon nanotubes.

commercially feasible—way to make millions of them. They also lack reliable methods for integrating nanoscale components. But these first steps provide compelling evidence that it is possible to build working nanodevices—and they have begun to generate considerable hope (along with a fair amount of hype) that Smalley's dream of building new materials with molecular precision will come true.

Turf Wars

WHAT HAS BROUGHT THIS DREAM WITHIN reach is researchers' new-found ability to image and manipulate individual atoms. In the early 1980s, physicists at IBM Research in Zurich invented the scanning tunneling microscope (STM), which made it possible for the first time to capture direct images of matter at the atomic scale. This was the discovery that opened up the nanoworld. Relying on the STM and a closely related instrument called an atomic force microscope (AFM), scientists can now directly push atoms and molecules about and prod them into place.

There are two forms of atomic manipulation. One involves physical manipulation to slide atoms around on a metal surface to form 2-D structures. The other approach attempts to fabricate stable structures with atomic resolution by breaking and forming chemical bonds, using the strong electric fields generated by the STM apparatus itself.

These are still exotic laboratory investigations. But for those in corporate and university research labs, the development of these powerful new tools means that "you can go hog-wild in imaging and manipulating entirely new physical structures," according to Donald Eigler, a physicist at IBM Almaden Research Center in San Jose, Calif. Eigler's group is, for example, studying the magnetism of several atoms perched on a surface. While the work using STM could eventually lead to advances in computing and magnetic data storage, Eigler is not driven only by practical applications. "What gets me most excited," he says, "is when I see an aspect of nature that has not been seen before. This is new turf."

Drexler offers a utopian vision. Few researchers doing actual experiments on the nanoscale have bought into it. But it holds a strong appeal for many others.

The boundaries of this new turf are still being drawn in a sometimes contentious debate. Most physical scientists report that nanospace is a mysterious place that operates according to its own rules. And even researchers like Smalley who believe the work will eventually pay off in significant benefits for society point out that they are just beginning to understand the physics of the very small and learn how to control behavior in this realm.

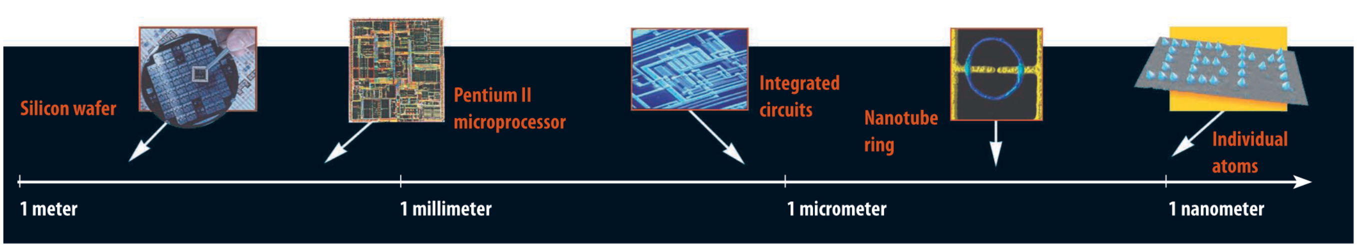
A few, however, maintain they have it all but figured out. For nearly two decades, K. Eric Drexler, chairman of the Palo Alto, Calif.-based Foresight Institute, a nonprofit group that aims to promote nanotech, has been describing in precise detail how nanomanufacturing will work—and change the world (see "Moses of the Nanoworld," p. 60). Drexler envisions self-replicating nanorobots that mechanically push atoms and molecules together to build a wide array of essential materials. Huge numbers of these nanorobots working together would supply the world's materials needs at almost no cost, essentially wiping out hunger and ending pollution from conventional factories.

It's a utopian vision that few researchers doing experiments on the nanoscale have bought into. But, not surprisingly, it holds a vast appeal for many others. This notion of nanotechnology has taken on a life of its own. And for a broad audience of technology enthusiasts, as well as for some in the media, it has become the best-known version of the nanotech dream.

That, according to some scientists, is exactly the problem. Drexler's ideas may have helped create early excitement for nanotech, but after years of hearing grandiose speculations of a brave new nanoworld, researchers say it's time to let the science overtake the fantasies. "There has been no experimental verification for any of Drexler's ideas," says Mark Reed, a nanoelectronics researcher and head of Yale University's electrical engineering department. "We're now starting to do the real measurements and demonstrations at that scale to get a realistic view of what can be fabricated and how things work. It's time for the real nanotech to stand up."

Some argue that the advent of practical nanotech is already here. It is a modest start. Scientists are not yet building practical electronic devices out of single atoms or molecules—and there are definitely no nanorobots around. But Richard Siegel, a materials scientist at Rensselaer Polytechnic Institute who headed a National Science Foundation-sponsored report last year on nanotech, says controlled synthesis of materials on a nanometer scale has already begun. The report also concluded that a worldwide race to exploit nanomaterials and build nanodevices is well under way, led by numerous university research groups and large industrial labs such as IBM Research, Motorola and Japan's NEC Fundamental Research (see "The Nanotech Nine," p. 53).

For now, these materials are mostly made by traditional methods of chemical synthesis, but Siegel says the availability of tools for atomic imaging has begun to



Size of stuff: Today's microelectronics are already tiny. Carbon nanotubes and other research devices could make it possible to get even smaller.

BETSY HAYES, PHOTOS COURTESY OF LUCENT TECHNOLOGIES, INTEL, IBM

Eyeing the nanoworld: Mark Reed wants to scale electronics down to single molecules.

enable scientists to make selective nanostructures. Siegel points, for example, to the development of nanocrystalline materials used in the giant magnetoresistance (GMR) devices that have in the past few years dramatically accelerated the pace of improvement in information storage. GMR technology relies on multiple layers of thin films, some only a few atoms thick; the precise layering of these thin films at the molecular level is responsible for the high sensitivity of the device. Siegel argues that "the huge impact of nanotech will come in nanoelectronics." The nanocrystals used in GMR, he suggests, are "only the tip of that iceberg."

For those making micrometer-sized devices (now common in advanced electronics and optics), the collision with the nanoscale is rapidly approaching. The expanding field of MEMs (micro-electromechanical machines), which is developing tiny machines to act as everything from microphones to miniature rockets, is also bumping up against the nanoworld and routinely making working parts as small as a few hundred nanometers.

For purists, however, you need to think smaller—much smaller—before you enter the real nanoworld. For these chemists and physicists, it is below about 50 nanometers where the fun begins. In this new arena, forces such as gravity that govern the everyday world rapidly lose their familiar meanings. "Physical intuition fails miserably in the nanoworld. You have to throw away your preconceived notions," says Reed. "You see all kinds of unusual effects." For one thing, electrons can go places that, according to classical physics, they can't be. In some cases, says Reed, "It's like throwing a tennis ball at a garage door and having the ball pop out the other side."

This is also where today's silicon-based electronics begin to fail. On the nanoscale, conventional transistors leak electrons like sieves, and the "dopant" atoms inserted into silicon to control its properties behave like huge, awkward boulders. Yet if the nanoscale poses sharp obstacles to conventional electronic technologies, it also opens up remarkable new possibilities that may leave today's electronics looking like the Model T.

If electronic devices could be reduced to the size of individual molecules, then

Building a backbone: Chemist Nadrian Seeman is looking for a way to construct DNA nanoscaffolding.

Nanofacturing with DNA?

Hanging from the ceiling above Nadrian Seeman's desk is a cube the size of a bird cage made out of loopy strings of different colored plastic—each string representing a strand of DNA. Scattered about the office are ball-and-stick models of octahedrons and other geometric shapes. Covering the chalkboard are colorful textile-like patterns.

Seeman, a New York University chemist, wants to use DNA as the architectural template on which to build nanoscale materials. He says the inspiration for the idea came to him in early 1980 when he was having a beer at a bar. Normally, DNA is a linear molecule, but he had been working on a four-armed branched variant. At the bar, he thought about an M.C. Escher woodcut of fish in space and wondered whether it might be possible to synthesize a similar 3-D periodic array using, instead of fish, branched, six-armed DNA molecules having "sticky ends" that allow them to bind to each other.

The nanotech part came later. But, for a chemist, it was obvious. If you could build an ordered scaffolding of DNA, you should be able to hang various molecules from precise points in the framework. In other words, use DNA as a geometric skeleton for assembling nanoscale materials. Unfortunately, Seeman says, building shapes out of DNA is something like playing with a set of Tinkertoys in which the blocks are marshmallows.

But last fall, Seeman and collaborators at NYU and Caltech published a paper in *Science* showing the self-assembly of DNA molecules into periodic, 2-D nanostructures. With this achievement, he gained confidence that he could extend such lattices into 3-D scaffolding that could hold everything from photonic materials to electronic components. In addition to nanoelectronics, he suggests, his work with DNA could offer ways to make the dream of molecular manufacturing come true. "We have plenty of schemes to take advantage of the properties of DNA to make little factories—ways to use the mechanical motion of organized DNA molecules to shuttle things along and process them."

But then Seeman becomes uncharacteristically subdued. As a scientist, he is clearly hesitant to speculate too wildly about the future implications of work yet to be done. "Right now it's in the realm of fantasy. In a couple years, I'm hoping it will be reality."

the game would be entirely altered. Molecular electronics was proposed in the 1970s by Mark Ratner, who is now at Northwestern University, and Ari Aviram of IBM. For years it remained a tantalizing idea far beyond the abilities of experimentalists. But during the past couple of years, leading-edge researchers have begun making actual wires and components out of single molecules. And now they have begun to make crude devices that actually work.

The development of molecular electronics would mean chips with billions of transistors and computers orders of magnitude more powerful than today's machines.

At Yale, Reed and his coworkers have, for one, made a diode out of several individual organic molecules. The simple diode, which is several nanometers long, is far from being a practical device, says Reed. But, he adds, it's a first, encouraging step to making transistors and logic devices at that scale.

Nanonoodles

ONE KEY TO THE ADVANCES IN MOLECULAR electronics could be an exotic molecule called the carbon nanotube. This remarkable carbon structure—discovered by researchers at Japan's NEC in 1991—is a close chemical cousin of the buckyball, a new form of carbon discovered by Smalley in 1985. But while the buckyball is a soccerball-shaped molecule of 60 carbon atoms, nanotubes are long pipes of a rolled-up sheet of graphite. They're electrically conducting and have been made into wires only a few nanometers in diameter.

Nanotubes are, both literally and metaphorically, a tunnel between the nano and macroscopic worlds. These structures make possible a long fiber that is only a few atoms wide. On a practical level, says Smalley, batteries might use nanotubes both to shuttle electrons between atoms and to carry a charge centimeters away. "Their great virtue is that they are molecular," says Smalley. Each nanotube, he says, is "an entity that has its own behavior and integrity." That means you can push the individual carbon molecules around, like tiny nanologs.

Actually, a nanotube acts a bit more like cooked spaghetti, says Phaedon Avouris, manager of IBM Research's nanometer-scale science and technology group in Yorktown Heights, N.Y. Each nanotube will stick to a surface and this adhesion is strong enough to maintain any shape you push it into. The adhesion also provides good electrical contact between the nanotube and metal electrodes.

Most recently, Avouris and his coworkers have maneuvered one of these "nanonoodles" to bridge a pair of electrodes and prodded the molecules into rings and letters. The IBM scientists have also made a functional field-effect transistor—a basic electronic device—at room temperature out of a single nanotube.

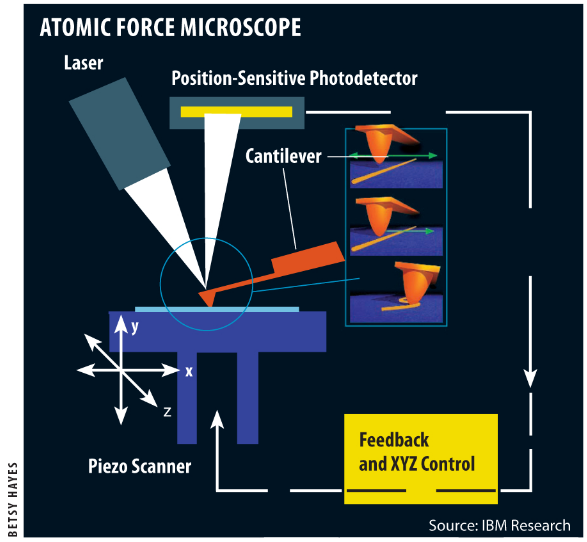
The successful development of molecular electronics would mean a single chip could hold billions of nanoscale transistors, making a computer orders of magnitude more powerful than today's machines. It also could mean building tiny and cheap computers that house millions of nanotransistors; such salt-grain-sized computers could be easily and cheaply incorporated into scores of other products—even into "smart" materials.

Nanotechnology could also make possible information-storage devices with immense capacity. Investigators at IBM Research in Zurich, led by physicists Gerd Binnig and Peter Vettiger, are building a micromechanical prototype that uses tiny silicon tips to read and write data bits that are less than 50 nanometers wide. That would translate into hard disks with storage capacities of close to a trillion bytes (terabytes)—a couple of orders of magnitude larger than the hard drives on today's top-of-the-line PCs. It could also mean small products, the size of a wristwatch, say, that have immense storage capacity.

In their experiments, Binnig and his co-workers use the AFM tip to read nanobits of information on a polymer surface. Using a single tip, however, would mean a process that's far too slow to be practical. Binnig has therefore wired arrays of more than 1,000 AFM tips that act in parallel. The arrays can rapidly write information by punching tiny divots in the substrate and read the nanobits by detecting the depressions.

Meanwhile, Binnig's colleagues at IBM Zurich have used the STM to turn out even smaller nanoobjects with clockwork precision. James Gimzewski, an IBM chemist, has built an exquisitely small abacus. Gimzewski used the STM tip as the "finger" to move the abacus beads, which are buckyballs with diameters of less than 1 nanometer.

Gimzewski's latest invention is a wheel constructed from a propeller-shaped molecule that spins on a tiny, bearing-like structure. Gimzewski says that while the rotating molecule suggests possible future nanomachines, the research



Moving a nanonoodle: The atomic force microscope (AFM) can both image and manipulate single atoms and molecules. A tip at the end of an extremely sensitive cantilever probes the surface. A laser beam reflects off the cantilever to a spot on a position-sensitive photodetector; as the cantilever bends in response to varying topography (or forces) on the surface, the spot moves and the displacement is read by the photodetector. In this setup, the AFM is being used to move around a carbon nanotube (inset). The tip applies a constant force on the sample and prods the nanotube into position; the cantilever provides input to a feedback circuit that keeps the force constant.

Surfing the Nanoworld

The Web is a tricky place to begin exploring the nanoworld. It is also one of the best.

First, there are the images—breathtaking views of single atoms and molecules that bring alive those old descriptions in chemistry and physics books. These are not just elaborate computer simulations but actual "pictures" obtained using the latest tools of the trade—scanning tunneling microscopes and atomic force microscopes. IBM Almaden Research Center's site, for example, presents a gallery of nanoscale structures—everything from a "quantum corral" showing a ring of iron atoms encircling and isolating single electrons, to the well-known image of the corporate name spelled out in xenon atoms (www.almaden.ibm.com:80~/vis/stm/gallery.html). For startling images of transistors made from single carbon molecules, click over to vortex.tn.tudelft.nl/~dekker/—a site maintained by Cees Dekker, a physicist at Delft University of Technology in the Netherlands and a leading nanoscience researcher.

The Web also provides a wealth of information on who's doing what in nanotech. A National Science Foundation-sponsored site (www.itri.loyola.edu/nanobase) provides an extensive database of the projects under way at industrial and academic labs around the world.

To understand molecular manufacturing, go to the page of the Foresight Institute (www.foresight.org), and the extensive home page of Ralph Merkle (nano.xerox.com/nano), a director of Foresight and computer scientist at Xerox Palo Alto Research Center. These sites contain extensive lists of academic, industrial and government research groups, as well as updates of the latest developments in the field. And there's no better place to learn about the ideas of K. Eric Drexler, Foresight's founder.

But be warned. You're now a click away from wandering into a proliferation of Web sites containing the musings and speculation of nanoenthusiasts. At www.foresight.org/Nanomedicine you'll find an explanation of how medical nanorobots will eventually swim through your blood vessels and crawl through tissues, making repairs as they go. Nanomedicine, you are told, will eliminate nearly all diseases and end medically related pain—not to mention giving you a mental boost by implanting data storage cells in your brain. Think that this might come too late to save you? Try cryonics, preserving your body until nanomedicine makes it possible to thaw it out and make the necessary molecular repairs (www.merkle.com/cryo/).

But why stop at ending disease? At nanotech.rutgers.edu/nanotech/Ufog.html, you learn that by linking together Drexler-style nanorobots into a solid mass, you could form objects in any shape you please. What's more, that object can change itself on command; the nanorobots simply reconfigure themselves. If you want, the style of your household furniture could change every day.

Around this point, you'll probably begin wondering: Haven't I crossed the line into science fiction? It's the question that sooner or later is bound to trouble anyone exploring nanotech on the Web.

remains embryonic. At this point, he says, "if you can get anything to work in the nanoworld, you don't worry about its practicality. We're just starting. It's like children playing with Legos."

The Zurich work reflects a deeply entrenched—and strongly Swiss—belief in mechanics. Physicist Binnig says, "Mechanics have been overlooked because electronics is so successful. It's considered old-fashioned." His device for information storage, however, works more or less like a tiny phonograph needle. As you explore the nanoworld, he says, mechanical devices become an attractive alternative to electronics.

Binnig says the mechanical approach can be extended well beyond data storage, and that "everything you can do electronically, you can do mechanically." Electronics are particularly good at guiding energy along precise paths to a well-defined place. But, he says, nanomechanics has an advantage of working with very low power consumption. While a 3-D nanoelectronics device would melt immediately from its own heat, Binnig says, you "could imagine" a 3-D nanomechanical device that would run cool. What's more, mechanical devices may prove easier than electronics to integrate with biological, optical and chemical systems.

Enter the Hype

IT'S SOMEWHERE AROUND HERE THAT THE science starts getting mixed up with science fiction. If you can make a nanowheel, why not a nanogear? A self-powered nanoboat? Why not build a nanorobot to move around the atoms for you?

And while you're at it, why not make nanorobots that can replicate themselves, making it possible to staff nanofactories capable of piecing together almost anything out of the basic building blocks of atoms?

Welcome to molecular manufacturing, as preached by nanoevangelist Drexler. At the core of the Drexlerian vision is a gizmo called an "assembler." This hypothesized robotic apparatus would work by mechanically positioning atoms into virtually any configuration. If the chemistry between the atoms doesn't take, the assembler would apply a small mechanical force (Drexler and his followers call it mechanochemistry). Get billions of these assemblers to work in parallel to arrange all the atoms just right—well, then, you can build just about anything you can imagine.

There's just one problem: Few chemists, physicists or materials scientists see any evidence that this will be possible. Many believers in the Drexlerian vision are computer scientists who delight in simulating how it all will work. They produce elegant molecular models of nanogears and pumps but offer no clear plan for how to actually build such things.

Proponents of molecular manufacturing aren't deterred by the skepticism of their more mainstream colleagues—although they do concede that their vision will take decades to be realized. Theoretical calculations and computer modeling say it can be done, insists Ralph Merkle, a computer scientist at the Xerox Palo Alto Research Center and a director, with Drexler, of the Foresight Institute. In particular, Merkle defends the two key proposals that have drawn the most fire from other scientists: the suggestion of self-replicating assemblers, and positional control of atoms and molecules to do mechanochemistry.

In self-replication, a molecular computer would direct the construction of a nanorobotic arm to build another computer; this second computer then directs the construction of another tiny computer, and so on. Self-replication is a concept that has been kicking around in computer science for years, says Merkle, and logically it should work. The idea of positional control calls for the robotic arms to precisely place atoms and molecules in a way that they bond, forming whatever you want. As long as you don't

violate any physical laws, Merkle says, this mechanical approach to chemistry makes sense.

But Drexler's critics point out that chemistry is a very complex process at the molecular level. To play the game of chemistry, says Smalley, means controlling atoms in three dimensions. At each reaction site, atoms feel the influence of a dozen or so neighboring atoms; to do mechanochemistry, you would need to control the motion of each one. For a nanorobot, that would be an inconceivably complicated juggling act. Other highly respected researchers simply dismiss Drexler's ideas out of hand. Says IBM's Eigler: "He has had no influence on what goes on in nanoscience. Based on what little I've seen, Drexler's ideas are nanofanciful notions that are not very meaningful."

Scientists still need to figure out a practical way to mass-produce any device on the nanoscale. Pushing molecules around one at a time is far too slow.

Assembly Lines

IN ANY CASE, BEFORE RESEARCHERS worry about building nanofactories, they need to figure out a practical way to mass-produce any device on the nanoscale. Some hope to make various exotic forms of lithography (optical lithography is the standard technology used to etch patterns on silicon chips) work below 100 nanometers. But how small—and how fast—lithographic methods could ultimately become is anyone's guess (see "Chips Go Nano," p. 55). Likewise, pushing molecules around one at a time using an STM is an exceedingly slow—and difficult—way to make anything. What's more, once you're done, you still have only one very tiny object. Building a single computer chip one atom at a time using today's STM technology would take, according to one estimate, 1,000 years.

One solution is to link up the STM or AFM tips in an array that works in parallel—a nanomechanical assembly line that might appeal to Henry Ford. This is the strategy IBM's Binnig is taking in his information storage device. And while wiring these tiny arrays and turning them into a working device is a chore, the preliminary research at IBM Zurich and several other labs suggests it just might work.

But many believe the longer-term answer lies in a process called self-assembly. Unlike the Drexlerian construction plan that uses self-replicating nanorobots to move atoms around, self-assembly relies on chemistry to position the pieces of a nanoscale structure, taking advantage of certain molecules' ability to arrange themselves in complex structures. In chemical terms, self-assembly works because molecules seek the thermodynamic minimum of the structure you want. Think of it as a prefab house that builds itself using chemistry.

But so far, chemists and materials scientists have learned to build only the simplest structures. The feat of assembling specific features in the materials and combining different materials remains a daunting challenge.

The solution to that problem could determine which nanodevices are practical—and how long it takes for them to hit the market. For most applications you would need to fabricate and integrate billions of nanoobjects. And to compete in such areas as information technology, you'll have to do it very cheaply. That, say many scientists, will require the synthesis prowess of chemistry. "Don't expect anyone to get to the point where you add ingredients in a beaker and out pops an integrated circuit," says Yale's Reed. However, the hope is that self-assembly could eventually place nanoelectronic devices "where you want them," Reed says.

That will take time. But there are encouraging signs that this approach will work. Self-assembly is, in a sense, where chemistry and materials science—the arts of building actual stuff—meet the physics of the nanoscale. Physics has provided scientists with the means to manipulate nanoobjects and understand the workings of the nanoworld, and now researchers are looking to chemistry and materials science for the next advances that will help turn all this work into a practical technology.

No one really knows where those breakthroughs will come from—or even if they'll come. But, as the science of the nanoworld grows, the shape of the real possibilities are beginning to emerge from the nanofog. ◊

The Nanotech Nine

U.S. companies hoping for a commercial payoff

COMPANY	STRATEGY
California Molecular Electronics 1997 startup; San Jose, Calif.	Develop molecular electronics.
IBM Research centers in Yorktown Heights, N.Y., San Jose, Calif., and Zurich	Basic research in nanoscience and nanomechanics to support computing businesses; developing prototypes for data storage.
Motorola Tempe, Ariz.	Development of molecular electronics and solid-state, quantum-effect devices.
Nanogen 1993 startup; San Diego, Calif.	Extend biotech expertise to the use of DNA for data storage and computing.
Nanologic 1997 startup; Walnut Creek, Calif.	Develop novel architectures for nanoscale devices.
Raytheon Systems Dallas, Tex.	Research on hybrid devices combining quantum-effect and conventional electronics.
Nanophase Technologies Burr Ridge, Ill.	Makes and sells nanocrystalline materials.
Hewlett-Packard Palo Alto, Calif.	Basic research in quantum devices.
Zyvex 1997 startup; Richardson, Tex.	Build an assembler for molecular manufacturing.

SOURCES: NATIONAL SCIENCE FOUNDATION'S NANOTECHNOLOGY DATABASE; MITRE CORP.; COMPANY REPORTS.

Chips Go Nano

Shrinking microelectronics have driven the exponential growth of Silicon Valley. That growth will stop unless computer chips can be made on the nanoscale. The big question: How?

BY DAVID VOSS
INFOGRAPHICS BY BETSY HAYES

FOR THE SEMICONDUCTOR INDUSTRY, WHAT started out as a cute description of a technology trend has become something like a force of nature. It's called Moore's Law. In fact, it's not a law at all, but a rule of thumb that Silicon Valley pioneer Gordon Moore cooked up back in the 1960s. Moore, cofounder of Intel, noticed that the number of transistors being packed into integrated circuits was doubling every year, and he predicted this trend would continue.

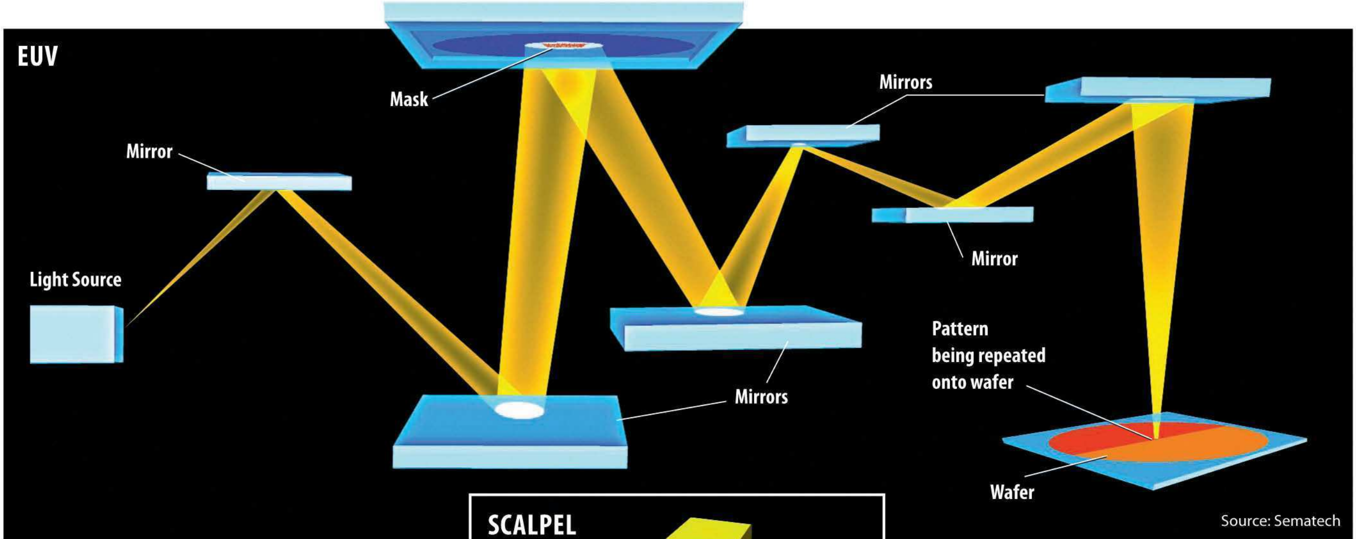
The strange thing is, it turned out to be more or less true. Moore's observation has become the de facto law behind the meteoric rise of the computing industry. Ever since 1975, the number of transistors on a semiconductor chip has doubled roughly every 18 months, enabling microprocessors and memories to get larger and more complex—and far cheaper. Powering this trend is the shrinking of transistors with each chip generation.

This rapid diminution of microelectronics makes possible today's information revolution. For chip manufacturers, the pace has been brutal but lucrative. "Throughout the 1980s," says Paolo Gargini, director of Intel's strategic research, new generations of chips "were on a three-year cycle. But in the 1990s, we've begun moving to a two-year cycle."

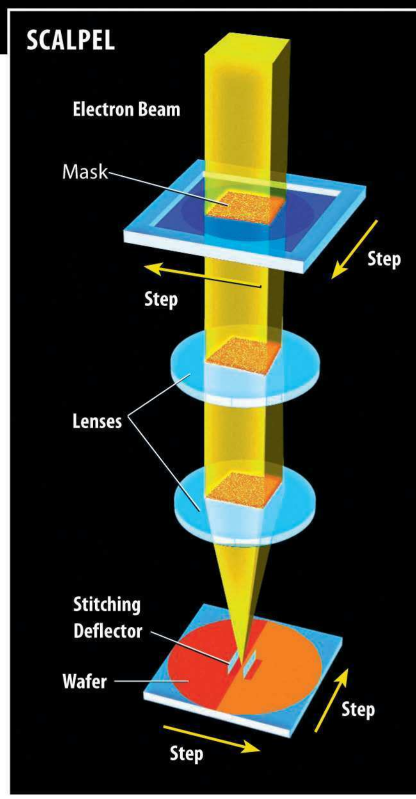
But the joyride can't continue forever—at least not with the technology now in use to make electronics. According to the latest roadmap charted by the Semiconductor Industry Association (SIA), the minimum size of features in integrated circuits will have to hit 130 nanometers by 2003 to keep pace with Moore's Law. That should be doable by adapting existing fabrication methods. But after 2003—the deluge. Following that year on the SIA roadmap is a lot of red, the color used by the trade association to indicate a lack of consensus about how to solve the fabrication challenges looming beyond the 100-nanometer barrier.

The problem is that the dominant technology used to make chips, optical lithography, uses light to carve silicon. Below 100 nanometers, however, the wavelengths of the light that is typically employed in chip fabrication become too large to do the job. Not that there is a shortage of possible alternatives to optical lithography. Indeed, every one of the large chip makers has its own favorite candidates. But no one is sure which method will win out. And since it takes several years to get a chip fabrication plant up and running, the clock is ticking.

In the meantime, the large semiconductor manufacturers are worried. "You always jump into these [new] technologies with the best of intentions," says Intel's



BETSY HAYES



Getting small: Both extreme ultraviolet (EUV) lithography (above) and Scalpel (left) use a mask to form a pattern in a photoresist covering a silicon wafer. In EUV, light with wavelengths of 1 to 40 nanometers is used; a series of mirrors focuses the light, allowing it to make features in the photoresist as small as 50 nanometers. Scalpel uses an electron beam, which is focused by a pair of lenses. The wafer and the mask are mounted on computer-controlled platforms, while the electron beam is stationary.

Gargini, "but until you can actually print circuits that you can sell, you never know."

In December, the companies that make up SIA and Sematech (the consortium of U.S. semiconductor makers) gathered to narrow down the choices. The 120 industry wizards in attendance picked two post-optical strategies for further development. The first choice was a photon-based technique called extreme ultraviolet (EUV) lithography, which is backed by a powerful alliance that includes Intel and Motorola; an electron-beam lithography method called Scalpel, under development by Lucent Technologies, was runner-up. IBM's candidate—X-ray lithography—came in third.

The decision has no binding effect—the companies can continue to develop any method they please. Indeed, rather than signaling a final decision, the voting points to the intense competition sure to come. "This will be the start of a big shootout over next-generation technologies," says Don Kania, chief technology officer at Veeco, a leading manufacturer of lithography tools. Adds Intel's Gargini: "The key thing is that instead of triplicating the effort, we can synchronize."

Silicon Snapshots

EACH OF THE CONTENDERS USES A DIFFERENT method to carve silicon, but they share a basic method: use of a stencil-like mask and basic etching techniques. Chips are now made with a gadget much like a large, highly accurate slide projector. Instead of blowing up your vacation pictures on the living room wall, however, an optical lithography machine shines light through an exquisitely crafted mask of the circuit pattern and images this on a layer of organic film, called a photoresist, that covers a silicon wafer. The organic film hardens on exposure to light; in the areas not exposed, the photoresist is washed off by solvents. This leaves regions of bare silicon that can either be etched to form channels or have other materials deposited on top to create the logic or memory elements in the integrated circuit.

The shorter the wavelength of light that is projected through the mask, the smaller the structures you can make on the chip. Leading chip makers, like Intel, have already moved deep into the ultraviolet region of light and use the 248-nanometer-wavelength light from a krypton fluoride excimer laser. This "deep UV" technology makes possible the etching of features as small as 200 nanometers and it is now being employed to crank out Intel's latest microprocessors, the Pentium IIs, each packing about 7.5 million transistors.

Extreme Measures

THE WINNING TECHNOLOGY AT THE December meeting, EUV lithography, is based on a simple premise: make the wavelengths even shorter, and the feature sizes will shrink in tandem. That, however, is easier to envision than to execute. For one thing, the wavelengths of EUV light—40 nanometers down to 1—aren't transmitted by any known materials, so conventional lenses are useless; the entire system must be made from reflective optics in order to focus the EUV light. There's no smoke, but it does rely on an extremely complex arrangement of very accurate mirrors.

"The mirrors have to have an unprecedented degree of perfection," explains John Bjorkholm, principal scientist at Intel's advanced lithography department. The surface roughness cannot exceed the thickness of a few atoms. For a mirror 2.5 centimeters in diameter, this is like plowing the United States flat from New York to San Francisco, making sure no bumps more than 4 centimeters high remain. And once

that problem is licked, the mirrors must be coated—bare metal or glass surfaces would absorb too much radiation. But, says Bjorkholm, "there has been exceptional progress" in manufacturing the mirrors.

The show-stopper for EUV, however, could be the mask. It's not that masks can't be constructed at this scale, but once they're made, there is no known scheme for fixing the defects that inevitably turn up in them. In commercial lithography schemes, designers routinely tweak individual elements in the mask to eliminate blemishes. For the reflective masks needed in EUV lithography, however, nobody knows how to repair these delicate, multilayer coatings. "Reducing these defects is the number one challenge," says Gardini.

Intel alone cranks out 100 million microprocessors every year. Any new technology has to feed this voracious production line reliably and cheaply.

EUV technology has been embraced by a consortium comprised of Intel, AMD and Motorola. These heavyweights have formed an entity called the EUV Limited Liability Company, which in turn has teamed up with three national laboratories in the United States to form a "virtual national lab" to develop EUV techniques. The group has already built a test system that can produce lines in a photoresist down to about 80 nanometers, and it has designs that should go down to 50 nanometers. The plan is to have a working prototype ready in the fall of this year.

Go Where I Send Thee

THE TECHNOLOGY THAT THE SEMATECH experts picked as runner-up, the Scalpel system being developed by Lucent, uses electrons, rather than light, to make the chips. Electrons are an alluring medium for etching because unlike light, they act more like particles than waves: They tend to go where you point them.

Lucent's decision to go with Scalpel is a simple matter of risk versus benefit, says Lloyd Harriott, program manager at Lucent. "We had programs in all the next-generation technologies, including EUV," he says. "In fact, we initiated the EUV technology back in the 1980s." That was at the old Bell Labs, and money for basic research was becoming tight. As a result, rather than playing the field, Bell Labs had to choose one lithography technique to champion.

Most of the other next-generation lithography technologies will need several breakthroughs before becoming commercially feasible, says Harriott. "If you look at Scalpel, the source is a filament, the optics are not much different from an electron microscope, and the photoresist is the same one currently used with deep UV lithography." To become feasible, he adds, Scalpel needs just one big advance: "The mask is the most unique problem." This is because Scalpel's mask is a radical innovation; the pattern is created in tungsten stuck on a thin membrane of silicon nitride, whereas conventional masks are made of chrome on glass.

Lucent built a proof-of-concept machine in 1996, and a lithography test bed in 1997 that can make features as small as 40 nanometers. The company is developing a commercial system that would be able to reliably make chips with 100-nanometer features that it hopes to market by 2002.

Still Breathing

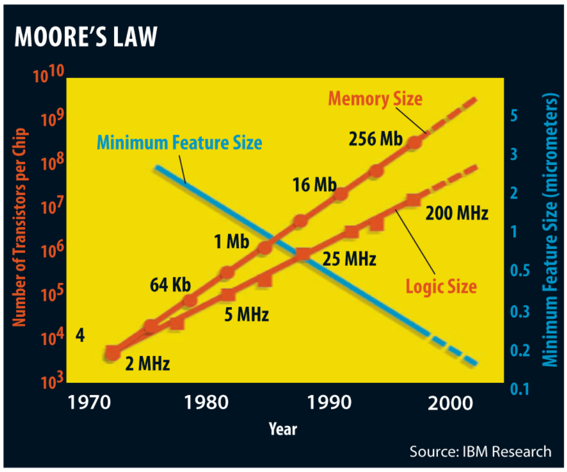
THESE METHODS ARE VERY PROMISING, and one or more of them will surely be the way to keep Moore's Law from going bust. Yet chip making is a notoriously conservative and financially competitive business, and companies won't embrace major change until the industry is painted into a corner. And, with the price of a new fabrication plant starting at around $3 billion, no one can blame them for wanting to be sure before betting all their chips on one particular number.

"If you were starting out today to design a car from scratch, the last thing you might choose to power it is an internal combustion engine," says Veeco's Kania. "But that is the current technology, and no automaker is going to change it until they're forced to." Likewise, chip makers are working hard to get every last nanometer out of optical lithography before turning to new technology.

Indeed, the most telling scuttlebutt at the Sematech meeting in December was that some in the semiconductor industry are thinking about staying with optical lithography for yet another generation of chips, using light with wavelengths down to 157 nanometers. This would allow them to make feature sizes as small as about 90 nanometers, breaking the 100-nanometer barrier. It would require substantial changes: new fluorine excimer laser technology, and optics made not of sturdy fused silica, but of delicate calcium fluoride. The extension could buy chip manufacturers a few years.

The semiconductor industry's reluctance to take a chance on new technology is understandable. Intel, the largest chip maker in the world, cranks out 100 million microprocessors every year. Any new technology has to feed this voracious production line reliably and profitably—something that optical lithography has been doing remarkably well for years. "Many times optical lithography has continued to surprise us by always pushing into another generation of chips," points out Intel's Gargini.

But sooner or later, the makers of integrated circuits will have to free themselves from optical lithography. That is, if they want to keep Moore's Law from being put under house arrest. ◊



BETSY HAYES

Upholding the Law: Manufacturers have squeezed more and more transistors on a chip, resulting in a steady increase in both computing logic and memory.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takes to read
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Moses of the Nanoworld

Eric Drexler led the way. But as the promised land beckons—in the form of better nanoscience—he may be left behind.

BY DAVID VOSS
PHOTOGRAPHS BY PETER MENZEL

IT'S A LOVELY NORTHERN CALIFORNIA DAY early last November, and you would expect K. Eric Drexler to be pleased. By almost any measure, his Foresight Institute's conference on nanotechnology is a raging success. After years of struggling to gain the respect of the mainstream research community, the meeting has hit the scientific big time.

This year's keynote speaker is Steven Chu, a physicist at Stanford University and recipient of the 1997 Nobel Prize for his work on manipulating atoms. The conference's technical sessions are packed with talks by some of the most prestigious names in chemistry, biophysics and materials science. Three days of presentations cover the latest work in carbon nanotubes, molecular wires, biomotors in living cells and nanofabrication. Out of about 300 registered attendees, roughly 40 are from corporate research groups, and more than 120 from academic or government labs. Even the National Science Foundation has sponsored a forum.

But Eric Drexler, the longtime popularizer of nanotech, is clearly not happy. Grasping the podium angrily, the chairman and founder of the Foresight Institute tears into his lunchtime speech, leading off with harsh words. "My mentor at MIT, Marvin Minsky, advocated rudeness as a means of promoting scientific progress," begins Drexler. He then proceeds to savage his critics, dismiss past magazine articles as "attack pieces," and bemoan the lack of serious research into nanotechnology.

Some of Drexler's remarks are tongue-in-cheek, such as when he reveals that the reason he has never been turned down for a federal grant is because "I haven't applied for any." But he is not joking when he maintains that "there is no controversy" over who's right about nanotechnology. There isn't a debate, he rails, there is just one side—his. Very small machines will be built, will make anything we want, and will transform civilization as we know it. What about those who dispute the vision? He says that he has asked people to give technical criticisms of his ideas and still hasn't found anyone whose arguments stand up.

The audience, a mixture of nanotech aficionados and professional researchers, listens in polite silence. No one rises to argue. Afterward, it's difficult to judge reactions. But some are clearly annoyed. Says one researcher, "I don't believe in anyone's utopia. It's too much like those magazine stories in the 1930s, predicting that all of us would be riding around in our little gyrocopters in the future."

Welcome to the nanotech culture wars. On one side is the Drexler-led contingent, which includes computer scientists, technology buffs and believers in cryonics; on the other side is the community of mainstream researchers in physics, chemistry and materials science. Despite Drexler's self-professed belief in the value of rudeness, however, there is little mudslinging in evidence at the Foresight meeting. Most of the back-and-forth is couched in the cautious words of scientific debate. Indeed, many in the research community simply prefer to ignore Drexler's ideas as an unwanted distraction.

There is, in fact, ample evidence at the conference that the two cultures—nanoenthusiasts and serious researchers—are floating past each other, largely oblivious to the other's ideas. But make no mistake about it: At stake is the heart and soul of nanotech—or, at least, the public's and mass media's perception of this fledgling field.

Since the early 1980s, Drexler has championed a utopian vision of synthetic molecular nanomachines made of subminuscule mechanical parts—actual gears and axles on the molecular scale—that would cure human illness, eliminate poverty and wipe away environmental pollution. Drexler has also warned that nanoweapons

Bringing nanodreams to the table: Eric Drexler has spent nearly two decades arguing molecular manufacturing will change the world.

unleashed against the world could wreak mass destruction. In short, it's a belief that nanotech will change everything.

In spite of his status as the field's foremost evangelist, Drexler didn't actually coin the word "nanotechnology." (Japanese researcher Norio Taniguchi created it in 1974 to mean precision machining with tolerances of a micrometer or less.) But Drexler brought the word and the field into the public mind, popularizing his version of molecular manufacturing in a 1986 book *Engines of Creation* and adding an exhausting level of detail in a 1992 book, *Nanosystems.* Both volumes depicted a future in which self-replicating nanorobots ("assemblers," in Drexler-speak) would manufacture batches of any material permitted by the laws of nature, one atom at a time. And, predicted Drexler, all this would come to fruition in a few decades.

Pursuing this vision, Drexler and Chris Peterson, his wife and professional partner, made the pilgrimage from the Northeast (both hold degrees from MIT) to the West Coast, founding the nonprofit Foresight Institute in Palo Alto in 1986. Their stated goal was to organize discussion of the technical and social implications of what they believe is a foregone conclusion: rapid change in the face of nanotech. The first Foresight meeting was held in October 1989 and attracted about 150 participants. At the first gathering, more than half of the talks covered proposed policy issues, computation theory, societal consequences of nanotech—and, of course, Drexler's ideas for the assemblers.

Since then, Drexler's notions have spawned a cottage nanoindustry that includes a Palo Alto-based Institute For Molecular Manufacturing (where he is a research fellow), a startup company, Zyvex, that intends to build Drexler's assembler, well-attended conferences, a small bookshelf of publications and—most recently—countless Web sites. And, lest you think this is a group far outside the boundaries of science, Drexler's vision has inspired dedicated followers among numerous computer scientists.

Despite that ever-widening circle of believers, however, Drexler's ideas have largely failed to win over the scientific mainstream *(p. 46)*. A number of researchers give Drexler and the Foresight Institute credit for generating interest in nanotech,

Clouded vision? Computer scientist Ralph Merkle says nanorobots moving atoms around will be the future.

but few experimenters in chemistry, physics or materials science buy the concept of mechanical assemblers inhabiting a microscopic factory floor. "I don't think that there is any more enthusiasm for most of these ideas now than at the beginning. If anything, less, as the real, science-based expertise in nanofabrication increases," says Harvard University chemist George Whitesides, a pioneer in molecular self-assembly. "Still, Eric was captivated by the vision early on, and he deserves credit for his willingness to try to imagine what that world might be."

In the face of a growing understanding of nanoscale cience, Drexler has steadfastly refused to change his original notion of a miniature robotic world.

One pointed criticism of the Foresight Institute is that, in the face of a growing understanding of nanoscale science, Drexler has steadfastly refused to change his original notion of nanotech as being a miniature robotic world. Although Drexler declined repeated requests by *TR* for an interview, his colleagues defend the assembler notion. Ralph Merkle, for example, a director of Foresight and a computer scientist at Xerox Palo Alto Research Center, says self-replicating assemblers with robotic arms moving atoms around remains the most likely route to the nanoworld. "Computer scientists are very comfortable with the idea," says Merkle. "You can do it on a computer." He acknowledges, however, it "will take time" to convince many chemists and physicists.

The Foresight Institute has also been tainted in the eyes of mainstream researchers by an association with fringe technological elements. It has, for instance, close ties with the cryonics movement, in which people pay to have themselves frozen immediately after death in the hope that they can eventually be thawed out and returned to the living. Merkle is a director of Alcor Foundation, a nonprofit cryonics business, while Drexler is on the scientific advisory board. (During his after-lunch speech at the meeting, Drexler called the fact that cryonics is not part of the country's health care policy a "national disgrace.")

This embrace of a decidedly non-mainstream notion may have alienated some potential allies, but Merkle says it is important to expose people to the consequences of cryonics, a technology he is sure will come about. And, he says, nanotech and cryonics may be linked up in the future. He argues that nanotech will revolutionize the practice of medicine as nanomachines repair damaged tissue. The purchasers of cryonics services, he explains, expect that their mental "software" can eventually be downloaded to the new, improved "hardware."

Not surprisingly, that argument leaves a lot of scientists cold. A number of those at the conference expressed a keen desire to move the science forward, and leave these distractions—and the past disputes—associated with nanotech behind. "The spotlight should be on the science, not on the personalities," says Reza Ghadiri, a biochemist at the Scripps Research Institute in La Jolla, Calif. "The character of the meeting has changed, and now the talks emphasize things you can test."

Could it be, then, that Eric Drexler is unhappy because nanotechnology has moved beyond him? Richard Smalley, a Rice University chemist and 1996 Nobel laureate who attended the Foresight conferences in 1995 and 1997, says Drexler "had a tremendous effect on the field through his books." But, Smalley adds, as the Foresight meetings have gotten scientifically better and better, "Drexler is now almost a bystander."

In the minds of many, the burgeoning field of nanotech is no longer identified with—or dependent on—Eric Drexler's vision of molecular manufacturing. The science has gained its own momentum, forming its own picture of a nanoworld. And while it may not meet Drexler's grandiose expectations, nanotech is, in some ways, growing bigger and more inclusive than many scientists would have ever thought possible. Yet in doing so, it may have left its conceptual progenitor behind. ◊

The Gene Factory

An exclusive peek inside the data machine built to beat the Human Genome Project.

By Karin Jegalian

ON A DAY OF VIVID HUES LAST FALL, AN ANXIOUS GROUP of architects, contractors, engineers and scientists gathered in the basement of a building in Rockville, Md. The structure was supposed to be converted by year's end into the greatest DNA sequencing factory in the world, but the planning meeting confirmed that problems were piling up. Delivery of a crucial steam generator had fallen behind. And it wasn't even clear that the walls of the 113,000-square-foot office building, which had been occupied by a defense contractor but now stood gutted, would accommodate all the pipes and wires needed to run the new laboratories.

The contractors were uneasy, but if the scientists present in the room weren't overflowing with sympathy, it was because they had set themselves an even bigger task with an even more dramatic timeline. The researchers work for Celera Genomics Corp., a company formed last May with plans to decode by 2001 all the 3.5 billion chemical letters of DNA that make up human heredity. Celera intends not only to beat by four years the target date originally set by the publicly funded Human Genome Project (which began in 1990), but also to finish the job for a tenth of the government project's $3 billion price tag.

If these claims were coming from another company, they might be dismissed as outrageous. But Celera is the child of Perkin-Elmer, the instrument company that monopolizes the market for automated DNA sequencing machines, and J. Craig Venter, the most controversial and productive genome researcher in the world. The partners agreed to give *TR* a preview of the substance behind their ambitious plan, and allowed a reporter to follow along as Celera's facility came into being.

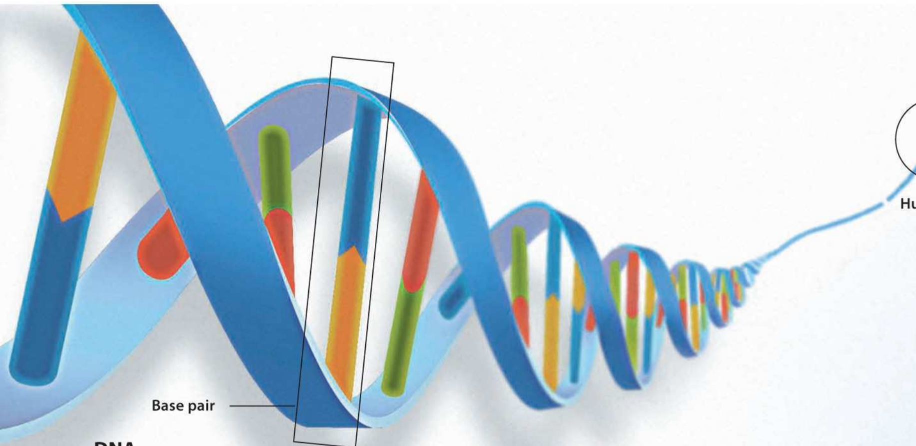
Much of the scientific expertise that powers Celera comes from The Institute for Genomic Research (TIGR), an independent lab Venter founded in 1992. At TIGR, also in Rockville, Venter's staff has employed a rapid-fire method known as the "random shotgun" approach to decode the genomes of nearly a dozen bacteria. No other lab has produced more DNA sequence—"readings" of the long strings of chemical letters designated A, C, G and T that make up the DNA molecule. Then again, Venter's approach has never been tried on anything as large as the human genome, which contains about 1,000 times as much DNA as your average microbe. "It's hard...to grasp the entire scale of this," says Venter, now Celera's president. "I can deal with millions, at least, because I spend them all the time now."

The money behind Celera comes from Perkin-Elmer, an instrument giant for which the project is a dramatic shift toward controlling data rather than just making and selling equipment. The decision by officials at Perkin-Elmer's Norwalk, Conn., headquarters to put a powerful new type of DNA sequencer to work for themselves has stunned the biotechnology industry and drawn comparisons to Microsoft's move into online publishing. The partners pre-empted fears that they might hijack the genome by promising to hand over the data for free (but with a few caveats) to the public sector. Between Venter's shotgun method and Perkin-Elmer's deep pockets and new machines, Celera looks as if it could well live up to its name: a play on the word *celerity,* for rapidity of action.

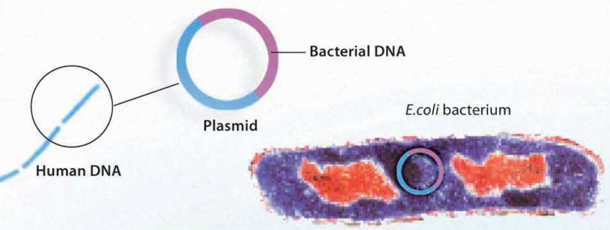
Factory Tour

TODAY, FOUR MONTHS AND MANY LATE NIGHTS AFTER the anxiety-riven planning meeting, the gene factory is complete. The only sign that the glass building contains what is arguably the world's most prolific molecular biology lab are two massive air conditioning units crouching in the grass. The chillers, too heavy to sit on top of the building, cool 1,600 cubic meters of air per minute and pipe it into the heart of the facility, where 257 new sequencing machines hum in orderly rows.

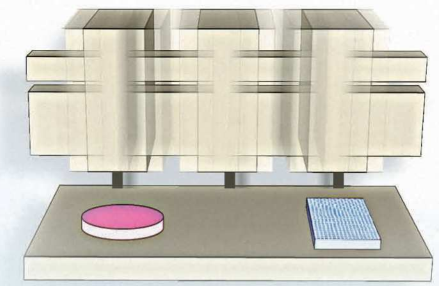
PHOTOGRAPH BY CHRIS HARTLOVE
INFOGRAPHIC BY BETSY HAYES



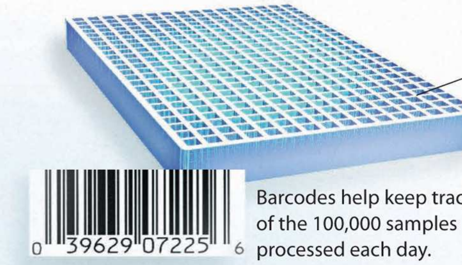
DNA
The human genome is made up of approximately 3.5 billion base pairs of DNA—composed of the chemical "letters" A, C, G and T.



Living Library
Each fragment is stitched into a ring of DNA called a plasmid, and stored in an *E. coli* bacterium for easy tracking and retrieval.



A robot uses a camera eye to pick colonies of the plasmid-carrying bacteria from petri dishes and place them into gridded lab plates that hold 384 samples.

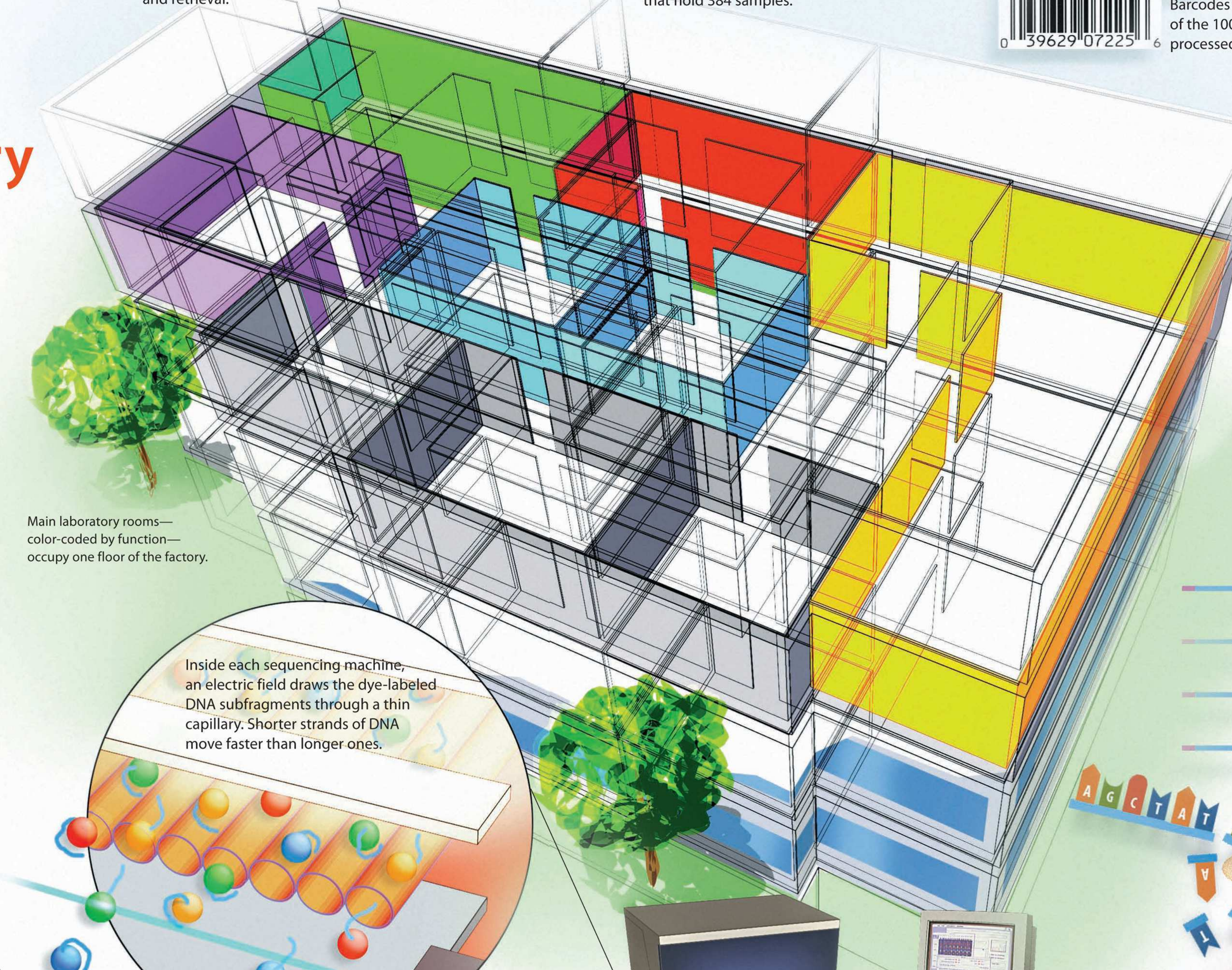


Barcodes help keep track of the 100,000 samples processed each day.

Copying the DNA
Technicians use a technique known as the polymerase chain reaction (PCR) to make millions of copies of each human DNA fragment.

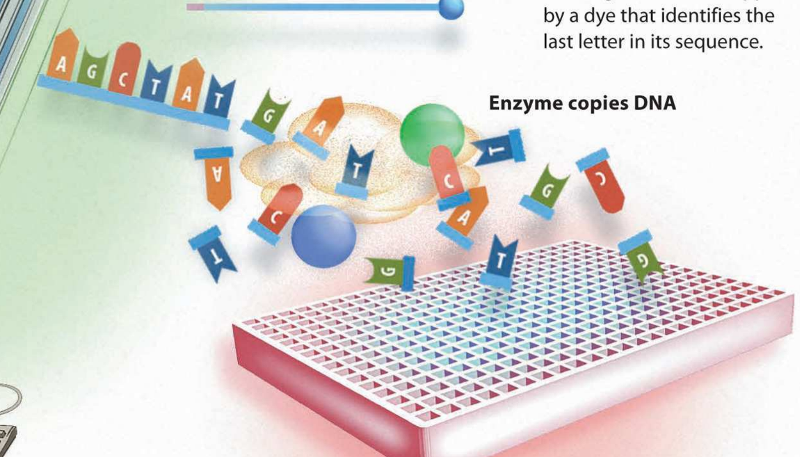
Inside the Gene Factory

Celera Genomics has built a 24-hour automated laboratory its founders say will decode the human genome in two years. As the set of all genetic instructions contained in our DNA, the genome establishes what we are as a species. Small variations between people influence how an individual looks and feels, and can explain susceptibility to diseases such as cancer.



Main laboratory rooms—color-coded by function—occupy one floor of the factory.

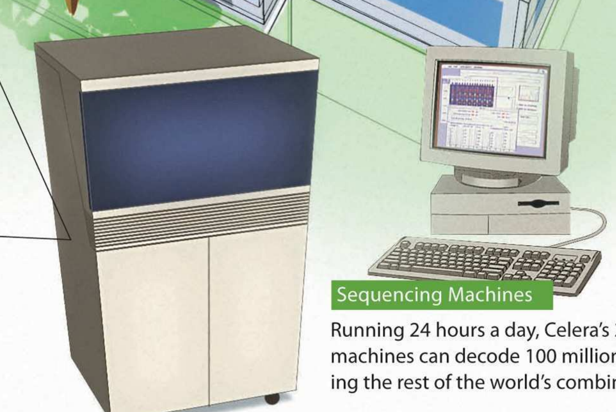
Sequencing Reaction
Next, 500 letters are copied from each end of the duplicate DNA fragments. This time, the copying reaction is fed with four fluorescent dyes as well as DNA's chemical building blocks—A, C, G and T. Each dye can substitute for one of the four DNA letters. When a dye is added, the reaction stops. The end result: A complete set of 500 staggered sub-fragments, each capped by a dye that identifies the last letter in its sequence.



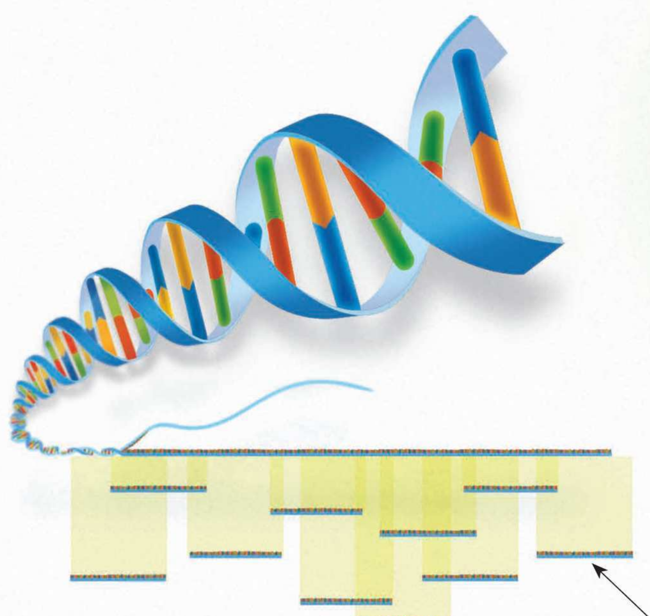
The sequencing reactions take place in a laboratory lit with infrared light that will not degrade the fluorescent dyes.

Inside each sequencing machine, an electric field draws the dye-labeled DNA subfragments through a thin capillary. Shorter strands of DNA move faster than longer ones.

As the subfragments seep out of the end of the capillary—shortest first—a laser beam detects the color of each dye. From the succession of colors, a computer reconstructs the original 500-letter sequence.



Sequencing Machines
Running 24 hours a day, Celera's 257 automated sequencing machines can decode 100 million letters of DNA per day, exceeding the rest of the world's combined sequencing capacity.

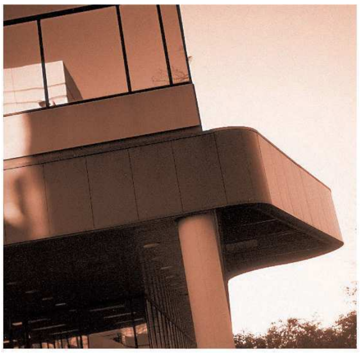


Sequence Assembly
Within two years, Celera's researchers plan to sequence 70 million 500-letter fragments of DNA altogether. To reconstruct the entire genome, they will have to assemble the jumble of decoded DNA in the correct order. Paired sequences taken from the ends of the same plasmid, as well as a high degree of overlap among the fragments, help to constrain this tough computational problem.

The principle computing facilities are located in a building adjacent to the main factory.

The gray, waist-high 3700-model machines were developed over two years in near-secrecy by Perkin-Elmer's West Coast subsidiary, Applied Biosystems. Just one of those machines, says Venter, has more sequencing capacity than many big academic labs, most of which rely on an earlier model called the 377. Altogether, Venter calculates, Celera can decode nearly as much DNA in one day as all the major labs funded by the Human Genome Project produced last year.

It's what's inside these new machines that makes them so fast. Each contains 104 glass capillaries: hollow, hair-thin tubes that the machine can automatically fill with a syrupy polymer and later clean out with a dilute solution of nitric acid. The sequencer's job is to sort DNA fragments by size. Pulled along by an electric field, small fragments move through the tubes faster than large ones. The capillaries replace cumbersome cafeteria-tray-sized slabs of toxic gel used in previous models, which had to be changed by a skilled technician every few hours. Stocked with chemicals and more than 1,000 DNA samples, the automated 3700 can run for nearly two days without human intervention, says Mark Adams, the young scientist who supervises Celera's sequencing operation. At full capacity, Celera expects to read 100 million letters of DNA sequence each day.



At full capacity, Celera expects to read 100 million letters of DNA sequence each day. More than half of Celera's personnel will be devoted to analyzing the avalanche of data.

More than half of Celera's personnel—backed by eight 6-foot, 64-bit computer servers located in an adjacent building—will be devoted to unscrambling the avalanche of data streaming from the sequencing facilities. Leading the analysis is Gene Myers, an expert on pattern analysis on leave from the University of Arizona's computer science department.

The challenge Myers' staff will face is something like reassembling a complete Bible from 10 copies that have been torn into tiny pieces. Since the sequencing machines can read only short stretches of DNA, the genome must first be broken into smaller pieces. Celera scientists began by taking DNA from a number of human cells and chemically shredding it into millions of random, overlapping fragments a few thousand letters long. To keep a library of these fragments, the scientists grafted them into colonies of *E. coli* bacteria. Following the shotgun strategy, Celera will then sequence 500 letters from each end of a fragment—repeating the process across the entire library yields 70 million separate sequences.

Myers' task is to develop algorithms that can assemble these elements once their code has been read. Although it sounds like a straightforward job—just line up overlapping letters and start pasting—it is anything but. Take the ripped-up Bible. Common phrases such as "Thou shalt not..." or "Blessed are they..." would make reassembling the good book much harder because some fragments appear to overlap when, in fact, they don't. The genome is similarly crammed with repeated sequences, some short, some long, some present in a million copies, others repeated only twice.

For that reason, scientists working on the publicly funded Human Genome Project have laboriously mapped out the genome before starting to sequence. Roughly like figuring out where the Bible's chapters go before tearing up the pages, it means they will then have to reassemble many small piles, rather than one huge one. Elbert Branscomb, director of the Department of Energy's Joint Genome Institute, thinks Celera's 70-million-piece puzzle may be unsolvable. "How much of a problem this will be no one even has a moderately good guess," says Branscomb.

Myers contends that the key to the solution is that Celera's puzzle pieces come in pairs lifted from the ends of a single fragment, the total length of which they know. The pairs, he believes, will constrain the problem enough to arrive at a unique solution. Outside scientists say Celera's strategy would be impossible without the sequences already developed at publicly funded labs, but Myers maintains the puzzle could be solved anyway. "Outside information is just an expedient," he says. "If we were going to do a genome that we have no data about, say Bermuda grass, we could do a self-contained operation."

Whether or not Celera's operation represents top-notch science is still a matter of some debate in the genome community. Without a doubt, Celera's version of the genome will have many, many small gaps. A photocopy, if you will, that gives the big picture and most of the detail but may fall short of the high-fidelity standard envisioned by the Human Genome Project.

After the Genome

THE DATA, HOWEVER, WILL BE GOOD ENOUGH TO TAKE TO MARKET. Venter has said he will give away the raw sequence for free by downloading it into the online public repository known as GenBank. So what's left to sell? Quite a lot. Celera's profits may come largely from licensing to pharmaceutical companies a database that packages the sequence into a more accessible form. Drug companies will mine the data for genes with medical applications, although Venter says Celera will first find and patent several hundred genes for itself. Celera will also hold onto information about single DNA letters that vary between people called "single nucleotide polymorphisms." These differences may predict a person's susceptibility to disease or to toxic drug reactions. And beyond the human genome lie others. Monsanto, the large agricultural concern, has already suggested that Celera take on the rice genome.

As Venter likes to point out, finishing the human sequence is simply the beginning of a new era in which the data can be put to use to improve human health. If Celera's plans work out, this "post-genomic" epoch will be upon us sooner than anticipated. In fact, Celera advanced the timeline for reading the genome before a single wall had been knocked down for the factory's renovation. Reacting to the unexpected competition, directors of the publicly funded Human Genome Project have announced that they now plan to knock off the entire project by 2003, two years earlier than the original schedule called for. And by 2001, when Celera has promised to unveil its data, public-sector scientists have vowed to come through with a "working draft" to match it. Public genome or private, celerity is definitely the order of the day. ◊

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$4,200,000,000 NETSCAPE has agreed to merge with America Online Pending	$1,850,000,000 BERG ELECTRONICS has agreed to merge with Framatome Connectors International Pending	$1,639,000,000 Seagate Software has agreed to merge its Network and Storage Management Group with Veritas Software Pending	$1,000,000,000 Boole & Babbage has agreed to be acquired by BMC Software Pending	$14,800,000,000 HBOC has agreed to be acquired by McKesson Corporation Pending	$300,000,000 Cambrian has agreed to be acquired by Northern Telecom Limited Pending
$196,000,000 IPEC has agreed to merge with Speedfam International Inc. Pending	ND Lucent Technologies Bell Labs Design Automation Group has agreed to be acquired by Cadence Design Systems Pending	$1,465,000,000 Rockwell has spun-off Conexant January 4, 1999	$37,000,000 RED BRICK has been acquired by Informix January 4, 1999	$540,000,000 USWEB has merged with CKS Group December 17, 1998	$55,000,000 APPLIED MATERIALS has acquired Consilium December 11, 1998
$128,000,000 VitalSigns SOFTWARE has been acquired by INS November 23,1998	$828,000,000 Stratus has merged with Ascend Communications October 19, 1998	$1,126,000,000 Texas Instruments sale of DRAM Assets to Micron Technology September 30, 1998	$260,000,000 AMBIT AMBIT DESIGN SYSTEMS has been acquired by Cadence Design Systems September 30, 1998	$9,100,000,000 Bay Networks Where Information Flows. has merged with Northern Telecom Limited August 28, 1998	$798,000,000 ARBOR SOFTWARE has merged with Hyperion Software August 24, 1998
$640,000,000 network ASSOCIATES has acquired Dr. Solomon's Group PLC August 13, 1998	$69,000,000 VeriSign has acquired Secure IT July 7, 1998	$9,600,000,000 COMPAQ has acquired Digital Equipment Corporation June 11, 1998	$287,000,000 AMERICA Online has acquired Mirabilis Ltd. June 5, 1998	$460,000,000 SCOPUS has been acquired by Siebel Systems May 19, 1998	$150,000,000 Healtheon has merged with ActaMed May 19, 1998
$300,000,000 network ASSOCIATES has acquired Trusted Information Systems April 28, 1998	$180,000,000 CommQuest Technologies, Inc. has been acquired by IBM March 13, 1998	$650,000,000 Livingston Enterprises, Inc. has been acquired by Lucent Technologies December 15, 1997	$1,115,000,000 McAFEE has merged with Network General December 1, 1997	$1,519,000,000 amdahl has been acquired by Fujitsu Limited September 18, 1997	$2,727,000,000 COMPAQ has merged with Tandem Computers Incorporated August 29, 1997

MORGAN STANLEY DEAN WITTER

Leadership in Technology IPOs

CONVERGYS *$195,000,000* *Initial Public Offering* *August 12, 1998*	EQUANT *$767,000,000* *Initial Public Offering* *July 20, 1998*	broadcast.com *$51,750,000* *Initial Public Offering* *July 16, 1998*	CELESTICA *$414,575,000* *Initial Public Offering* *June 29, 1998*	i-Cube TRANSFORMING THE BUSINESS WORLD *$34,500,000* *Initial Public Offering* *June 22, 1998*	Amdocs *$252,000,000* *Initial Public Offering* *June 19, 1998*
ACG *$57,557,500* *Initial Public Offering* *May 28, 1998*	ZD ZIFF-DAVIS *$400,000,000* *Initial Public Offering* *April 28, 1998*	ARM POWERED ARM Holdings plc *$131,000,000* *Initial Public Offering* *April 17, 1998*	BROADCOM *$96,600,000* *Initial Public Offering* *April 16, 1998*	RELTEC *$183,425,000* *Initial Public Offering* *March 12, 1998*	VeriSign *$48,300,000* *Initial Public Offering* *January 29, 1998*

Leadership in Technology Financings

@Home Network *$200,000,000* *Convertible Subordinated Debentures* *December 18, 1998*	Healtheon *$44,000,000* *Private Placement of Series E Preferred Stock* *October 30, 1998*	ARROW ELECTRONICS, INC. *$250,000,000 Senior Notes** *October 22, 1998* *$200,000,000 Senior Debentures* *May 29, 1998*	BROADCOM *$238,050,000* *Common Stock* *October 20, 1998*	MOTOROLA *$325,000,000* *Notes* *October 15, 1998*	COPPER MOUNTAIN *$25,000,000* *Private Placement of Series D Preferred Stock* *October 9, 1998*
@Home Network *$132,600,000* *Common Stock* *August 12, 1998*	EDS *$475,812,500* *Common Stock* *August 10, 1998*	ASPECT *$150,214,400* *Zero Coupon Convertible Debentures** *August 5, 1998*	AMERICA Online *$549,780,000* *Common Stock* *June 29, 1998*	excite *$85,050,000* *Common Stock* *June 10, 1998*	ST STMicroelectronics *$1,371,562,500* *Common Stock* *June 5, 1998*
INGRAM MICRO *$460,419,330* *Zero Coupon Convertible Senior Debentures** *June 4, 1998* *$414,000,000* *Initial Public Offering* *October 31, 1996*	Intuit *$462,000,000* *Common Stock* *May 21, 1998*	HADCO *$200,000,000* *Senior Subordinated Notes** *May 13, 1998*	JDA Software Group, Inc. *$105,800,000* *Common Stock* *May 6, 1998*	amazon.com *$325,987,100* *Senior Discount Notes** *May 5, 1998*	ZD ZIFF-DAVIS *$250,000,000* *Senior Subordinated Notes* *April 28, 1998* *$1,350,000,000* *Senior Secured Credit Facilities* *April 1998*
DELL *$500,000,000* *Senior Notes and Debentures* *April 22, 1998*	ATMEL *$115,004,140* *Zero Coupon Convertible Subordinated Debentures** *April 16, 1998*	CSG *$165,080,160* *Common Stock* *April 7, 1998*	Sapient *$91,200,000* *Common Stock* *March 31, 1998*	I Integral Capital Partners *$302,000,000* *Integral Capital Partners IV, L.P.* *March 27, 1998*	ASML ASM Lithography *NLG 600,000,000* *Convertible Subordinated Notes** *March 20, 1998* *$268,106,250* *Ordinary Shares** *January 23, 1997*
ARBOR SOFTWARE *$100,000,000* *Convertible Subordinated Notes** *March 11, 1998* *$35,190,000* *Initial Public Offering* *November 6, 1995*	Western Digital *$460,129,000* *Zero Coupon Convertible Subordinated Debentures** *February 11, 1998*	network ASSOCIATES *$346,150,000* *Zero Coupon Convertible Subordinated Debentures** *February 10, 1998*	Rockwell *$800,000,000* *Senior Notes* *January 21, 1998*	IBM *$700,000,000* *Debentures* *January 6, 1998* *$1,000,000,000* *Senior Notes and Debentures* *July 30, 1997*	SanDisk *$84,000,000* *Common Stock* *November 18, 1997*

MORGAN STANLEY DEAN WITTER

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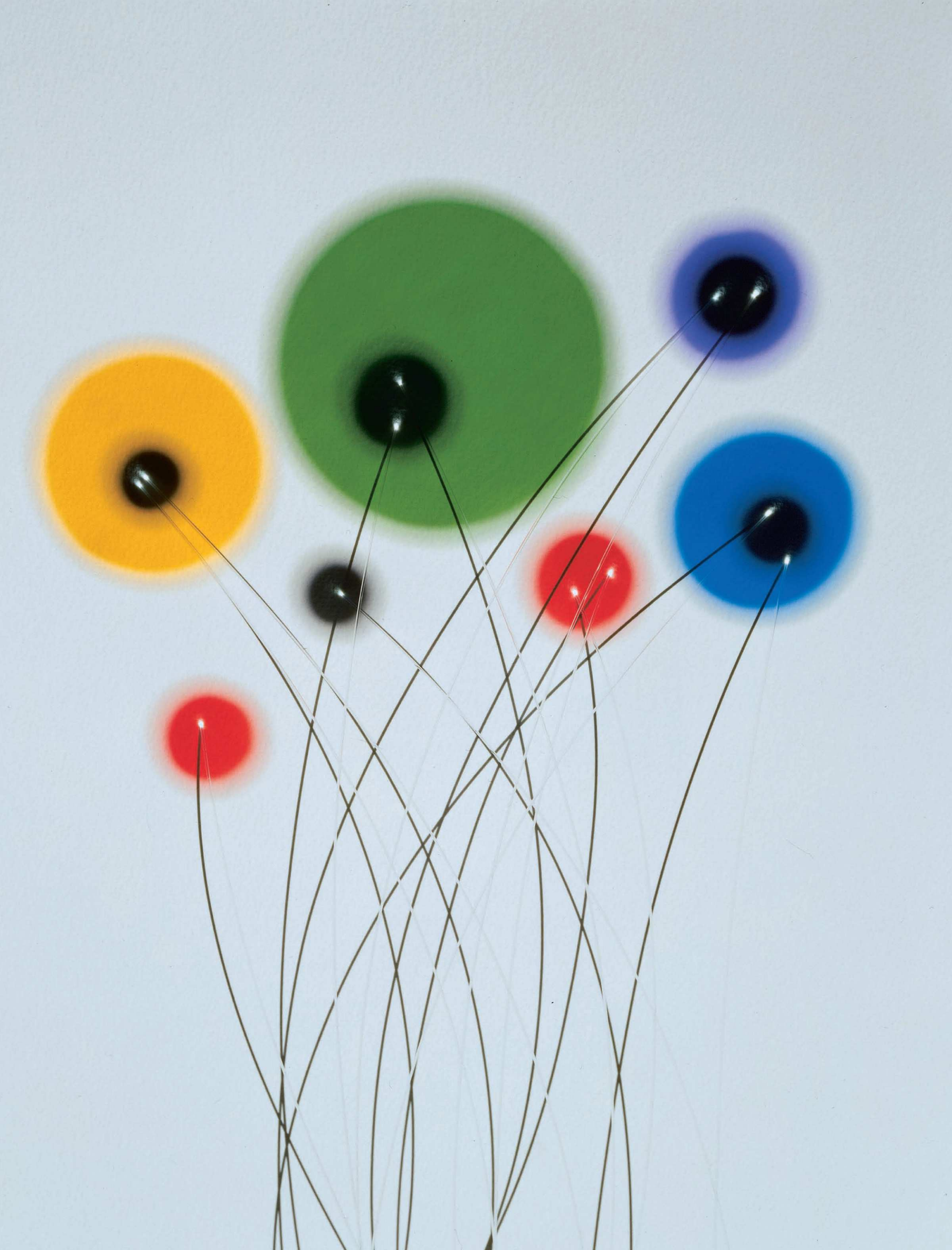


Wavelength Division Multiplexing

What's that, you ask? A new technology that's opening vast realms of capacity in the fibers that carry phone and Internet traffic all over the world. None too soon, either. BY JEFF HECHT

Bandwidth in communications is like closet space in your home—you can never have enough. And Internet traffic is making the demand for communication capacity grow faster than the wardrobe of a teenager with a no-limit credit card. Bandwidth-hogging megabytes of animated graphics are replacing compact e-mail messages. Data, video and voice signals crowd transmission systems that had ample space just a few years ago. The communications industry needs room to breathe.

That's exactly what a new generation of fiber-optic technology is bringing to networks such as the aptly named Project Oxygen. Neil Tagare, founder of the CTR Group in Woodcliff Lake, N.J., picked that name for the global network because he considered the tremendous bandwidth offered by the new technology to be as vital for telecommunications as oxygen is to life itself. By sending signals at 16 different wavelengths through each of four pairs of optical fibers, Project Oxygen will carry 640 gigabits per second (Gbit/s) across whole oceans. That's the equivalent of 10 million simultaneous telephone conversations—enough for every person in Hungary or Belgium to call the United States at the same time.

The technology that makes this new bandwidth possible is called wavelength division multiplexing, or WDM, and it represents the second major fiber-optic revolution in telecommunications. The first came during the 1980s, when telephone companies laced the United States and other countries with fibers to create a global backbone of information pipelines that could carry vastly more data than the copper wires and microwave links they replaced. WDM takes this advantage a giant step further—multiplying the potential capacity of each fiber by filling it with not just one but many wavelengths of light, each capable of carrying a separate signal.

Wavelength division multiplexing has emerged "quite conveniently, as older fiber cables were getting filled," says Richard Mack, vice president at KMI Corp., a Newport, R.I.-based market analyst firm specializing in fiber optics. Taking advantage of WDM, long-distance carriers such as AT&T and MCI have been able to avoid laying expensive new cables; instead, they simply pump additional wavelengths through existing fibers.

PHOTO-ILLUSTRATION BY PIERRE-YVES GOAVEC

The WDM revolution has arrived with unanticipated swiftness. A decade ago, Mack points out, "people said there was a glut of fiber capacity." To allow room for expansion, phone companies had laid cables containing 24 to 36 fibers, many held in reserve as "dark fibers." Each fiber carried hundreds of megabits per second at a single wavelength. Since then, carriers have raised data rates to 2.5 Gbit/s and lit most of the dark fibers. But the tremendous increase of traffic has crowded these cables that once seemed so voluminous. The closets, it seems, are rapidly being packed to the rafters—and stuff is spilling out onto the floor. Telephone usage accounts for some increase, including the spread of fax machines and mobile phones. But the most dramatic growth has been from Internet traffic, which roughly doubles each year.

What's also clear is that there's no end in sight to the soaring demand, especially if, as many experts believe, two-way video communication becomes more common. "The communications industry is undergoing a transition that in a few years shall bring us digital video for our everyday use at home and at work," says Shahab Etemad, who heads WDM transmission development at Morristown, N.J.-based Bell Communications Research, or Bellcore. (Initially the research arm of the local and regional phone companies, Bellcore now operates as a network management consultancy with a variety of corporate clients.) Etemad expects the change from voice telephony to digital data heavy with video to require multiplying backbone transmission capacity by about a factor of 200—and, he insists, WDM "has to play the leading role" in meeting that expanded demand.

Thanks to advances in WDM methods, fiber has done a good job in keeping up with this explosion in demand. According to David Clark, senior research scientist at MIT's Laboratory for Computer Science, "The ability to get bits down a fiber is growing faster than Moore's Law," which predicts the doubling of computing power every 18 months. At the moment, Clark notes, the carrying capacity of fiber is doubling every 12 months.

Doing It with Erbium

The term "wavelength division multiplexing" reeks of engineering jargon, but the concept is simple: simultaneously send separate signals through the same fiber at different wavelengths. Essentially the same idea forms the foundation of radio and television broadcasting, where each station sends its signal out on an assigned wavelength in the radio-frequency spectrum. Of course, most people think in terms of frequency instead, but the two values are inextricably bound by their relationship to the speed of light. (For instance, 100 megahertz on the FM dial corresponds to a wavelength of about 3 meters.)

The same principles work for the light going through an optical fiber as for radio waves transmitted through air. Optical fibers transmit best at the invisible, near-infrared-light wavelengths between 1.3 and 1.6 micrometers—roughly double the wavelength of red light.

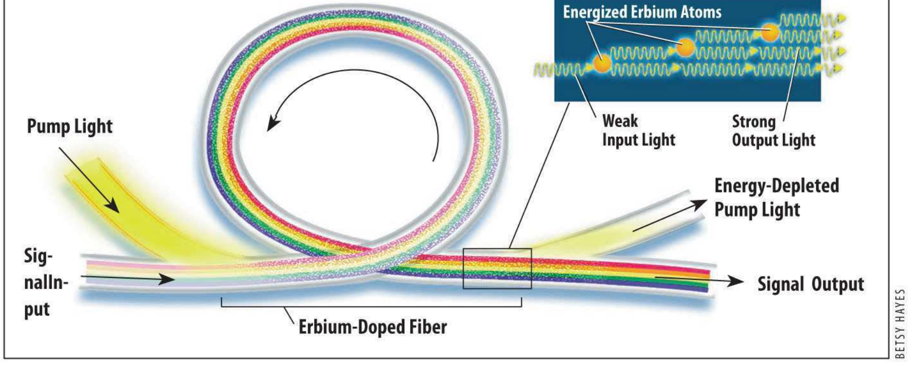
If WDM is both straightforward and an idea that's been around—why has it only recently become practical? The biggest obstacle has been the lack of suitable amplifiers. Light signals traveling through even the most transparent optical fibers fade to undetectable levels after a couple hundred kilometers. For most of the time fiber optics have been in place, the only way to span fibers longer than that was to regenerate the signal through an optoelectronic process: A photodetector would convert the stream of weakened light pulses into a voltage signal that could be amplified electronically; this boosted signal modulated a laser transmitter.

The problem is that light detectors don't discriminate between wavelengths—they scramble signals at different colors, much the way your ears have trouble discerning what is being said if two people talk at once. For optoelectronic systems to work with multiple wavelengths, they must have a way to separate the wavelengths optically, using filters or other similar elements, enabling each signal to pass through its own regenerator. Until recently, though, that has proved impractical.

This limitation disappeared with the invention of a technique for boosting the signal light's intensity directly, without the need for an intermediate electronic step. The key piece of technology is something called an "erbium-doped fiber amplifier." These devices, developed in the late 1980s, made the WDM revolution possible.

Unlike a regenerator, a fiber amplifier operates directly on light. Light in the feeble input signal stimulates excited erbium atoms in the fiber to emit more light at the same wavelength. Chains of optical amplifiers can combine to carry signals through thousands of kilometers of fiber-optic cable on land or under the ocean—without regenerators. Because they preserve the wavelength of the optical signals, erbium fiber devices can amplify several different wavelength channels simultaneously without scrambling them. Erbium amplifiers work well across the near-infrared region of the spectrum at which fiber-optic systems operate.

HOW AN ERBIUM AMPLIFIER WORKS



On Land and in Sea

Long-distance telephone companies were the first to realize that wavelength division multiplexing could cut the cost of bandwidth. Compared with the alternative of adding new fiber, WDM technology provides "a much more effective way to add capacity," according to Dana Cooperson, optical network analyst for RHK Inc., a market consultancy in South San Francisco. Laying new cable is expensive and time-consuming. And burying new cable along the same route already occupied by an older cable is risky—new excavation invites cable breaks that could put the whole system out of service.

Telecommunications companies avoid laying expensive new fiber-optic cables by pumping multiple wavelengths through existing fibers.

The telecommunications carriers' desire to save time and money has driven a rapid development in WDM techniques. In the mid-1990s, the carrier companies began using systems transmitting at four wavelengths, and soon upped the count to eight. Developers quickly sliced the spectrum even more finely to squeeze 16 wavelength channels through a single fiber for what has become known as "dense" WDM.

When the carriers saw the need, manufacturers were equally quick to sense the market. Lucent Technologies of Murray Hill, N.J., adapted technology developed at its Bell Labs subsidiary. Ciena, a Linthicum, Md., company founded in 1992, charged ahead faster, delivering its first commercial 16-channel system in 1996—at nearly the same time as the AT&T spinoff. Other telecom giants around the world followed, including Nortel, Alcatel, Pirelli, NEC, Hitachi, Fujitsu and Ericsson. Over the past two to three years, several companies—including Ciena, Lucent and Nortel of Saint-Laurent, Que.—have begun to market systems that slice the erbium-amplifier spectrum into 32 or 40 slivers, each only 0.8 nanometer wide. Last September, Lucent delivered its first 80-channel system to AT&T. Pirelli Cable of Lexington, S.C., followed by promising a 128-channel version, but had not delivered hardware as of mid-December.

Telecommunications carriers don't need all those channels today—and thanks to WDM's inherent modularity, they don't need to buy more channels until they're ready. A carrier installing a WDM system can start with only the transmitters and receivers needed for the few initial channels. Later, as demand for capacity grows, additional equipment can be plugged in to open up new wavelengths.

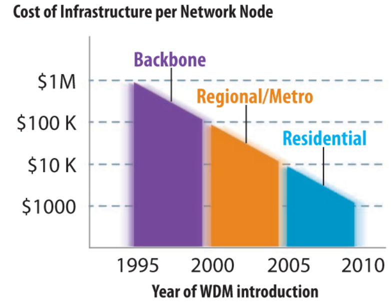
Taking full advantage of WDM often requires upgrading older cables by adding components that compensate for a troublesome effect called chromatic dispersion. This refers to the tendency of a short light pulse to stretch out as it travels through a fiber owing to the fact that some wavelengths travel faster than others. Dispersion smears light pulses together and therefore limits transmission speed. Avoiding this phenomenon is especially important in submarine cables, where light signals must travel through several thousand kilometers of fiber from shore to shore. New installations can exploit fibers designed for optimum WDM performance, recently developed both by Lucent and by Corning (Corning, N.Y.).

Last year, the first big submarine cable designed for multiwavelength operation—called Atlantic Crossing 1—began sending 2.5 Gbit/s at four wavelength channels on each of its four fiber pairs. The capacity of this system can be upgraded to 16 wavelengths per fiber at that speed, says Patrick R. Trischitta, director of technical marketing at Tyco Submarine Systems Laboratories in Holmdel, N.J. That promises a total of 160 Gbit/s through the cable, a loop connecting the United States with Britain, the Netherlands and Germany.

Project Oxygen raises the bar. Newer WDM technology will carry 10 Gbit/s at each of 16 wavelengths across the ocean in four fiber pairs, a total capacity of 640 Gbit/s per cable. That's more than 1,000 times the capacity of the first transatlantic fiber-optic cable, which began service just a decade ago. The whole system will ultimately include 168,000 kilometers of cable—enough to circle the globe four times. Other groups are planning more submarine cable systems, although none is quite so ambitious. It's no wonder MIT's Clark predicts, "We're going to drown in fiber."

MULTIPLEXING MOVES IN

Cost of Infrastructure per Network Node



Source: AT&T Labs

BETSY HAYES

On land, regional telephone companies have just begun to adopt wavelength multiplexing. Last year, Bell Atlantic began testing WDM on a 35-kilometer cable between Brunswick and Freehold, N.J., says Robert A. Gallo, the Bell Atlantic engineer in charge of the trial. Four channels each carried signals at speeds to 2.5 Gbit/s—the top rate between company switching offices—and the Ciena-built system has slots for up to 16 wavelength channels. Bell South tested three of 16 channels in a similar system on a cable spanning 80 kilometers between Grenada and Greenwood, Miss.

The economics are clear: "It's cheaper to add WDM capacity than to add new fiber," says RHK analyst Cooperson.

Different rules apply to the shorter cables linking switching offices to major business customers. Here, in the so-called "metro" market, "the cost of increasing fiber count is not as big an issue because the runs are so much shorter," Cooperson explains. Still, WDM improves signal transmission in other important ways. One is by carrying signals in their original digital formats rather than converting them into the digital coding used within the telephone network. Because such conversion requires costly electronics, it can be cheaper to dedicate a wavelength for end-to-end transmission in the original format.

The ability to sort signals by wavelength should streamline the operation of future fiber-optic networks. Traditionally, phone companies organize digital signals in a hierarchy of bit rates, merging many low-bit-rate tributaries into mighty digital rivers carrying gigabits per second. This packs bits efficiently onto transmission lines, but requires unpacking the whole bit stream to extract individual signals. If the signals are organized by wavelength, however, simple optics can tease out the desired wavelength channel without disturbing the others. Engineers speak of adding a new "optical layer" to the telecommunications system. Customers might lease a wavelength in this optical layer instead of leasing the right to transmit at a specific data rate. A television station, for instance, could reserve one wavelength from its studio to its transmitter and


NORTH ATLANTIC
PACIFIC

another to the local cable company—and transmit both signals in digital video formats not used on the phone network.

The Ultimate Squeeze

Since the demand for bandwidth shows no sign of slowing down, the developers of WDM systems are already thinking about how to pack more wavelengths into the same fiber. At the moment, there are two basic approaches being investigated—and limits to both are apparent.

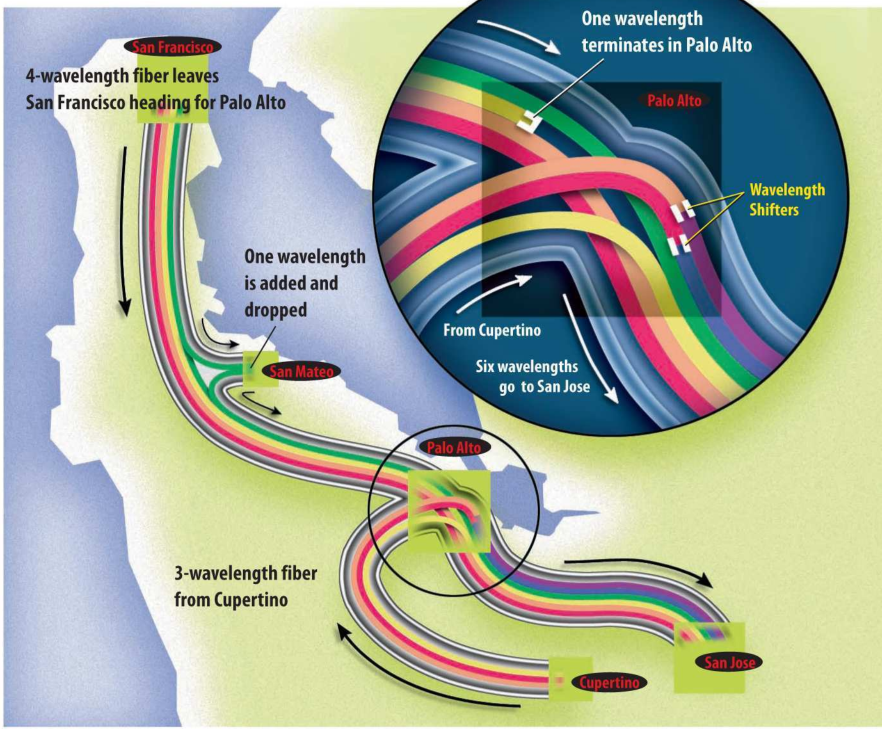
One approach is to reduce the "space" between wavelengths, by choosing wavelengths that are closer together to carry the multiplicity of signals. Packing wavelengths closer works well up to a point, but it ultimately clashes with basic physics. As bit rates increase, optical pulses get briefer, and—following the dictates of Heisenberg's Uncertainty Principle—this shortening forces the light signal to spread over a broader range of wavelengths. This spreading can cause interference between closely spaced channels. Lucent's highest-capacity system handles 10 Gbit/s on wavelength channels separated by 0.8 nanometer but only 2.5 Gbit/s when channel spacing is halved. And few experts think channels can be squeezed much tighter. Among major vendors, only Hitachi Telecom of Norcross, Ga., talks about modulating individual channels at 40 Gbit/s—and admits that those signals could span only limited distances.

Prospects look better for the second option: expanding the range of transmission wavelengths. Pirelli, for example, uses three erbium-fiber amplifiers, optimized for separate bands between 1,525 and 1,605 nanometers, to squeeze 128 wavelength channels at 10 Gbit/s each into a single fiber. Lucent has demonstrated erbium amplifiers covering a similar range in the laboratory, and last year introduced a new optical fiber that opens up a long-neglected block of the spectrum around 1,400 nanometers. Good optical amplifiers are not yet available for other wavelengths.

For WDM to reach its full potential, though, more will be needed than simply packing in additional wavelengths. It will also be necessary to develop better equipment for switching and manipulating the various wavelengths after the signal emerges from the optical "pipe." Optical switches "are getting close to practical commercial applications," says analyst Mack of KMI. He adds, however, that "to fully emulate what happens in digital cross-connects, you need to reallocate and reassign wavelengths." It's impossible to allocate the same wavelength to one customer throughout an entire system because the huge network has far more customers than it has wavelengths.

The illustration below shows how signals from San Francisco and Cupertino arrive in Palo Alto at the same wavelength, both bound for San Jose. The Palo Alto node must convert one signal to a different wave-

A WDM SCENARIO



BETSY HAYES

length for the final leg of its trip, so that the messages they carry aren't hopelessly confused. Wavelength conversion now must take the same brute-force approach as regenerators, converting the optical signal to an electronic one that can drive a transmitter at the output wavelength. All-optical conversion approaches, while demonstrated in the lab, have yet to reach commercial practicality.

Even if these technical problems are solved, however, that won't be enough for the technology to really spread its wings. For that, the price will also have to come down—a trajectory that insiders say has already become apparent. Adel Saleh, head of the broadband access research department at AT&T Labs in Red Bank, N.J., projects that cost per network node will drop by a factor of 10 every five years, starting at $1 million in 1995. Through the next year or two, he says, WDM will be economical only for backbone networks. Once cost drops to $100,000 a node, the technology will make sense for metropolitan and regional networks, starting with service to large businesses. Saleh expects that residential access in large apartment buildings will follow after costs drop to $10,000 a node in about 2005, with WDM reaching individual homes once costs decline to about $1,000 in 2010.

The real strength of WDM lies in how it expands the optical airways so that everyone can inhale more of the oxygen of information. At the dawn of the radio era, each transmitter screamed across the whole radio spectrum, blocking other signals for the duration of its broadcast. Then engineers learned to build circuits that tuned each transmitter to its own frequency, opening the radio spectrum to the many stations we can hear today. In much the same way, WDM replaces a single stream of black-and-white bits with a multitude of different-colored signals.

WDM is creating huge new information pipelines that will bring better service at lower cost. But the real information revolution won't come until cheap WDM pipelines reach individual residences. Today's modem connections remain bottlenecks, forcing us to sip the torrent of data through the electronic equivalent of a thin plastic straw. But get ready: As fiber reaches the home, your very own wavelength could deliver a bubbling fountain of bits. ◊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What Are the Rules, Anyway?

If you're puzzling out how to prosper in the networked information economy, Carl Shapiro and Hal Varian have some advice.

Q & A

The freewheeling economy of the World Wide Web may seem like a lawless place—a frontier town without rules. Not so fast, say economists Carl Shapiro and Hal Varian. While technologies come and go, they argue, the laws of economics persist. As a result, the new moguls of the Web can—and should—learn from the past. Content providers can learn from Hollywood's mistakes; e-commerce sites can take lessons from L.L. Bean; Bill Gates can discover that hundred-year-old antitrust laws apply even to him.

In their new book, *Information Rules* (Harvard Business School Press), Shapiro and Varian offer up a practical introduction to the economics of selling information. Shapiro and Varian explain how to maximize the value of intellectual property, differentiate products, lock in customers, negotiate standards alliances, and benefit from so-called "network effects"—the idea that the value of some goods depends on the number of people who use them. Telephones are the classic example of such a product, and in the Web age, network effects seem pervasive. It is network effects that stimulate the positive feedback that allows Microsoft's market share to grow and grow.

Shapiro and Varian first connected in the mid-1970s when Varian was a professor at MIT and Shapiro an undergraduate. Varian is now dean of the University of California at Berkeley's School of Information Management and Systems, and Shapiro is Transamerica Professor of Business Strategy at Berkeley's Haas School of Business. During 1995-96, Shapiro served as chief economist in the Department of Justice's antitrust division; he has since consulted with the U.S. government on the Microsoft case. Freelance writer Becky Waring caught up with them recently on the Berkeley campus.

PHOTOGRAPHS BY TIMOTHY ARCHIBALD

Information rule-makers: Carl Shapiro (left) and Hal Varian.

TR: Why are network effects so important these days?

SHAPIRO: Look at Microsoft. Arguably their operating system is not all that great—it's buggy and it has problems—and yet they still have a 90 percent market share. In time, their position might erode, but they have a lot of inertia due to the size of their installed base of users.

TR: Why does selling information require a different set of rules from selling physical goods?

SHAPIRO: Because the economics of information is different. Think about a book or a movie. There's a huge upfront cost to create the content and then very little to make additional copies. That's even more so with the Internet, where the information is in digital form and can be distributed at virtually no cost to large numbers of people. This is not the case with manufactured goods, where there is a substantial cost to produce and deliver each unit.

VARIAN: Another difference is on the demand side. Buyers of information goods really don't know what they're getting until they experience it, and by then they've already paid for it. The challenge that faces information providers, then, is this: How do they tell you what they've got without giving it all away? This is not a problem that's unique to the Internet. Movie previews, book reviews, music radio and so on have helped solve this problem in the predigital world. Now we're beginning to see the Web equivalents.

TR: Supposedly, the Web is going to allow us to get rid of the middleman and allow a free flow of goods and information. But aren't you just trading one intermediary for another?

SHAPIRO: Yes—we like to say that the friction-free economy is a fiction. With e-commerce, the reputation of the seller, whether it's L.L. Bean or Lands' End, will be even more important than in the past because people are all the more concerned about things like the security of the transaction, the quality of the merchandise, service and support. Sure, people will be able to shop around efficiently for the lowest price—but reputation is always going to be very important, and that's where middlemen come in. Take stock trading sites, which offer an inexpensive and convenient way to buy and sell securities. A lot of investors have realized that saving a small amount on a transaction isn't worth much if the trade isn't going to be executed properly or if they're not getting good prices. A number of brands will survive, and some will be cut-rate. Right now, we're in a shake-out phase.

TR: What's the main problem facing old-line companies still struggling to understand Web commerce?

VARIAN: Incumbents in any industry have to grapple with their old business models. Take music retailing—record producers would love to sell directly to consumers, but they don't want to alienate their traditional distribution channels. A company that comes along without a pre-existing distribution channel to preserve—like Amazon.com, for instance—can be much more flexible.

SHAPIRO: Of course, there's nothing to bar conventional retailers from competing online as well. Look at the bookselling business. Barnes and Noble didn't lead, but it pretty quickly followed Amazon.com. I think that's a pattern we'll see over and over: upstart entrants establishing a way to use the Net that works, and then the incumbents following along saying: This may cannibalize some of our existing business, but if we don't do it, others will.

TR: What industries do you see as being the most threatened by the Web, or conversely, having the most opportunity to gain by learning the new rules?

VARIAN: CD-ROMs and the Web allow for a much cheaper way to distribute huge volumes of information. This forces traditional companies to radically rethink their strategies. Look at the encyclopedia business. Encyclopedia publishers have decades of experience selling at high prices to a small number of buyers. Now along comes the Web, making it possible to reach a much larger market—but also forcing a drastic reduction in price. It's very hard to give up those high-priced sales in the hope of getting a lot of low-priced sales, but that's what these companies have to do. The same goes for distributors of nationwide telephone directories. Just 10 years ago, the first CD phone directory sold for $10,000 a copy. Now you can buy one for $3.99—or get the numbers free on the Web.

TR: How do you recommend that companies get the most out of their intellectual property in the Web era?

VARIAN: Many companies fall into the trap of thinking that they should maximize the *protection* of their property. Your real goal should be to maximize its *value*. When videos first came out, the movie industry was frightened out of its wits. Moviemakers tried to preserve the old business model by selling only to the high end of the market. Hollywood didn't realize that low-price, mass-market videos could be very profitable. Now, video sales and rentals account for more than half of Hollywood's revenue. On the Internet, you can increase the value of your products to the consumer by making your terms and conditions more liberal. Of course, this means you might sell less of it. The question is which of those effects will dominate.

TR: Having just published a book, you're in a position to test this out for yourself.

VARIAN: Yes, and we recently signed a contract with Rocket E-Book to publish the book in electronic form. Clearly there's a danger there—people might copy the text and give it away, undercutting book

Five Key Rules

- **Exploit the "network effect" that causes a product's value to rise along with the number of people who use it. Promote user-to-user interaction so that people see the value of using what their friends and colleagues use, and publicize market share information to create a powerful aura of inevitability.**
- **Differentiate your information product. Information is costly to produce, but cheap to reproduce. To maximize the value of intellectual property, produce targeted versions that reach as many people as possible.**
- **Don't overprotect your property. Give away samples of your goods to potential customers, but not the whole store.**
- **Lock in users by making it costly for them to switch brands. Use proprietary features and coordinate your strategy with your business partners.**
- **Cooperate, even with your competitors, on industry standards that benefit all.**

The friction-free economy is a fiction. In e-commerce, the seller's reputation is all the more important.

sales. On the other hand, electronic books have a huge potential, and the users are the sort of technological leaders that we're after, so we think it's very sensible. We're also posting a chapter on Amazon.com: If you want people to consume your information, you have to give them a good idea of what you have to say.

TR: A lot of Web businesses are offering "personalized" service, which requires that they gather information about each customer. Do you see a conflict between personalization and privacy?

VARIAN: I think there's only an apparent conflict. The real question is whether the firms truthfully disclose what they will do with the information; consumers have a right to know how information about them is going to be used. If those uses have sufficient value to them, and they trust the technological and legal infrastructure to make sure that their information is used in a secure way, both buyers and sellers can be better off with some information disclosure. It's hugely beneficial for people who supply things to me to know quite a bit about me—as long as they don't abuse that information. Right now we're in a transition stage where we don't have the institutions to guarantee that trust, so there is some abuse of the system. Ultimately, this is going to require some regulatory oversight.

SHAPIRO: We've been waiting for industry to get its act together and do this on a voluntary basis. If they don't work something out pretty soon, government will need to step in. But intervention ought to be light-handed—aimed at providing options and flexibility rather than restrictive mandates.

TR: What would be the most important issues the government should focus on to enable the new economy to work smoothly?

VARIAN: My top three are intellectual property, privacy and Internet governance. The main worry I have about intellectual property is that it's driven by the content providers, who are putting a lot of lobbying money into strengthening copyright laws to cope with the Internet. With privacy, the danger is getting railroaded into a bad policy as a way to placate a public outcry. The Communications Decency Act, for example, was a knee-jerk reaction to the threat of online pornography. Finally, the governance problems facing the Internet are huge; they're difficult enough at the national level, yet they ultimately require international coordination. I think that we're going to see a lot of wasteful legal suits by disgruntled participants in the next few years.

SHAPIRO: Another thing the government has to keep an eye on is antitrust. I take the view that the legislation passed a hundred years ago has now been elaborated. The basic legislation said, "You can't monopolize a market. Don't stifle competition." Now we have a hundred years of court decisions explaining what that means. This legal structure is, I think, quite flexible: It has handled many new industries and new technologies. If there's a worrisome area there, it's sorting out the boundary between antitrust and intellectual property. One troubling decision, for instance, essentially forces Eastman Kodak to license its patented technology for servicing high-volume photocopiers. I'm doing work for Intel now and I'm concerned about the Federal Trade Commission's action against Intel as a precedent for forcing companies to divulge intellectual property under conditions they would not agree to voluntarily. [The FTC accused Intel of violating antitrust law by denying its customers technical information they needed to develop computer systems based on Intel microprocessors.]

TR: Say "antitrust" and most people are going to think of Microsoft.

VARIAN: The press has focused on Microsoft vs. Netscape or Microsoft vs. Sun. But the real role of antitrust is not to choose winners but to define the rules of the game. The most important outcome of the Microsoft case is going to be the precedent it sets for future competition.

SHAPIRO: The challenge for antitrust is: Do network effects lead to durable monopoly power? And in the presence of network effects, what conduct stifles competition and innovation? Linux is out there as an alternative operating system that's quite good, but it doesn't yet have critical mass. Can it really take off and succeed? This is not a new issue. In the 1950s FTD, the floral service, tried to impose a rule that a florist could not join another network if it wanted to be a part of FTD. The Justice Department said, basically, not so fast—you guys have a monopoly over floral networks, and that's exclusionary. And so FTD agreed to drop that provision, the same way the Justice Department is now asking Microsoft to drop provisions that make it difficult for America Online to distribute Netscape.

VARIAN: The point is that if you're in a race, it's fine to run as hard as you can, but it's not fine to trip the other guy. The important thing is to make sure that you have appropriate rules of conduct for those firms that end up having dominant market positions.

SHAPIRO: Microsoft says in its defense: We have to run as fast as we can because technology is changing. If we slow up or don't give good value to our customers, we're going to be out on our ear.

TR: Is that true?

SHAPIRO: I don't think so. In any event, Microsoft is running down the racetrack, and certainly improving its product, but the question is whether some of its tactics are designed to stiff-arm competitors. And that's the role of antitrust law: to make sure that competition is not blockaded, and then let the consumers decide. ◊

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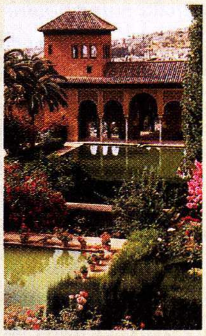

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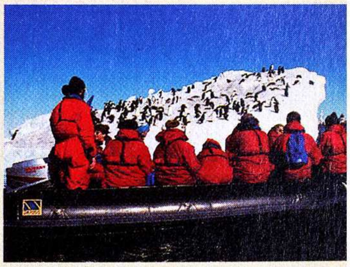

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That's Immortality!

WHAT'S SO GREAT ABOUT IMMORTALITY?

That impertinent question occurs to me in the aftermath of recent news reports about the long-awaited isolation of human embryonic stem cells. A group of researchers at the Geron Corp. in Menlo Park, Calif., announced this sensational discovery in the waning days of November (although readers of *Technology Review* were treated to a fascinating advance story by Antonio Regalado in last year's July/August issue).

Embryonic stem cells are being packaged for popular imagination as microscopic fountains of youth. These primordial cells retain the ability to develop into every cell type in the body—skin, liver, heart muscle, neuron—if correctly coaxed by the right biological signals.

But just what would life be like with unlimited access to replacement body parts? I sought (with apologies to Mel Brooks) some answers from an imaginary muse I'll call The 200-Year-Old Man. When my researchers found him, he was living in—where else?—Miami Beach.

"So how's it feel to be 200 years old?" I asked.

"WHAT?" he yelled. "Did you know I was at Woodstock? They let me in free, just for keeping people away from the amplifiers."

"So why haven't they fixed your hearing?" I yelled back.

"Turns out that's one of the things they haven't figured out how to grow. Didn't you just ask something?"

"I just wondered how it feels to be 200 years old."

"Can't complain. Well, actually I *can,* and that's one of the best parts. You live so long, you keep meeting new people who haven't grown tired of hearing you kvetch. It's great!"

"Where do you keep your stem cells?"

"Right up there on the mantle, next to the bingo trophies. In that little tank."

"Do you have to feed them?"

"You use this fetal calf serum stuff. You used to have to order it through biological supply houses. Now they sell it at Costco, in 55-gallon drums. A 'lifetime supply.' *As if they knew!*"

"How many different organs have you been able to grow from your cells?"

"Did you just ask something?"

"I said, 'How many different organs have you received?'"

"Lemme see. I got a new liver, a new heart, a pair of new hamstrings, and then a new pair of ankles."

"So it's like a combination of Sears and *Gray's Anatomy*—you basically order anything you want out of the catalogue."

"Well, that's what I thought at first. But having the stem cells is only part of the deal. See, they gotta be able to send signals to these cells to tell 'em what to do. I don't wanna get too complicated for you here, but the point is, they know how to make some organs and not others. So I've been waiting on a new set of brain cells for quite some time. Did you just ask me something?"

"Uh, no."

"Another thing they haven't figured out is skin."

"Yeah, it looks a little dry."

"A little like parchment is what you mean. And these polka dots? Liver spots. Hey, you try playing golf for 130 years and see what kind of a complexion you have. But the problem isn't liver spots. Every time you get one of these new organs, they don't tell you that you gotta have an operation. And every time you have an operation, you get these scars. I look like Raggedy Andy.

I know a guy who got a penile transplant, so he can get physically excited like a teenager. But they can't yet grow neurons, so he either forgets what to do or falls asleep.

Another thing they never tell you is that they may have figured out how to grow one kind of tissue, but not another. I know a guy who got a penile transplant, so he can get physically excited like a teenager. But until they can grow these neurons, he either forgets what to do or falls asleep. Another time, after I got my hamstrings, I'm like a bull, I want to go out and run a mile in four minutes. And I was doing great for the first couple of minutes."

"And then what happened?"

"That's when I broke both ankles."

"Would you say stem cells have given you a new lease on life? What have you done with all the extra time you have?"

"Oh, lots of stuff. I read the papers. Watch reruns of *The Honeymooners.* Play golf. I still get into arguments with my kids, but it's gotten a little ridiculous. I mean, how do you ground someone who's 160 years old?"

"I hope you don't take this the wrong way, but it doesn't exactly sound like the most interesting life."

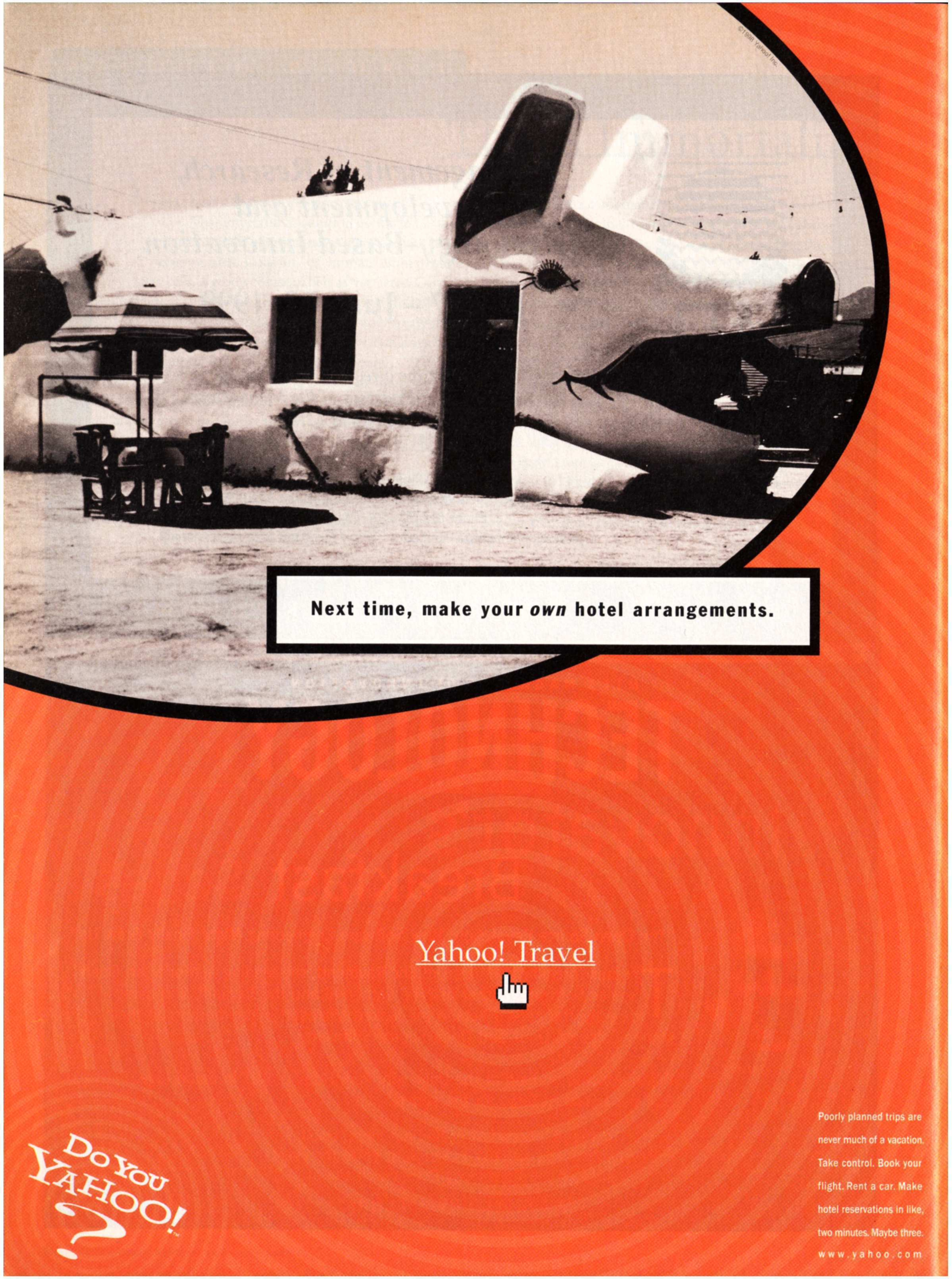
"You ever hear of a guy named Lonesome George?"

"The turtle on the Galapagos Islands? Sure. The one that's 100 years old."

"You know what he does all day long?"

"If I recall correctly, he doesn't do anything. He just moves around real slowly and then stops and sleeps for a while and then moves a little bit more."

"That, my friend, is immortality." ◊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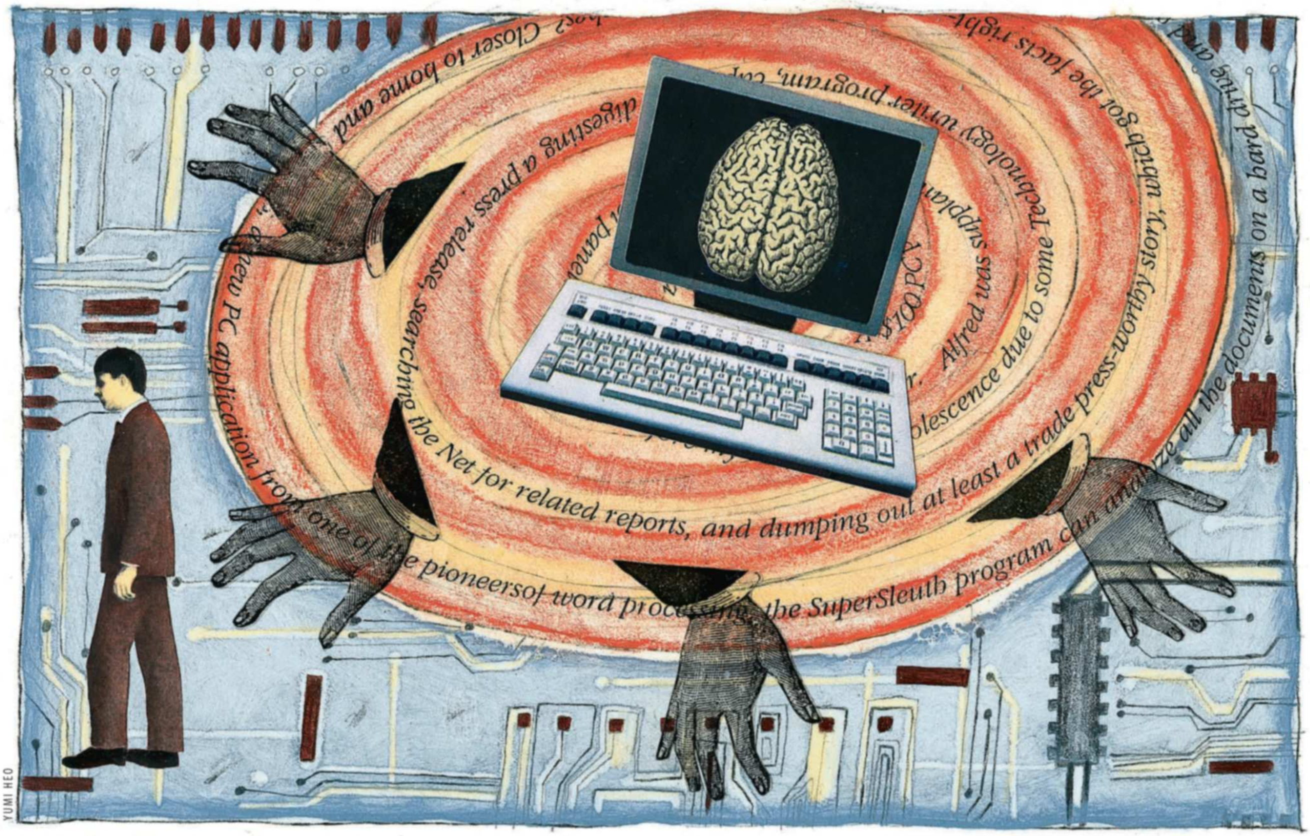

YUMI HEO

VIEWPOINT | BY STEVE DITLEA

The Write Stuff

In Which the Author Worries: Can I Be Replaced?

My earliest memory of obsolescence was the sudden disappearance of Alfred, the Maltese-born elevator man in the small Manhattan loft building where my father's firm made plastic business novelties. One day, when I was eight and visiting my dad's office (always a treat because I could pound away on his industrial-strength typewriter and fantasize about a writer's life), the elevator was out of commission and Alfred was no longer around. It took three months before an automatic elevator was running, but Alfred would never return.

He was supplanted by buttons on a control panel and relays behind a rudimentary computing system that couldn't replace Alfred's extra-elevator skills as a daytime watchman, neighborhood information resource, and thoroughbred racing tout extraordinaire. After he was gone, there were thefts in the building as well as frequent breakdowns of the automated elevator, but never any talk of bringing Alfred back.

One morning five years ago a story on the front page of *The Wall Street Journal* gave me the shock of my life. I got from it that computer software was about to make my profession obsolete, that I was to suffer the same fate as Alfred and the other elevator operators whose work has disappeared. I was in a panic.

My profession consists of writing about technology for periodicals in print and online. (All right, it's not strictly a profession—I didn't have to do graduate study for it and I'm not licensed by the state, like dentists and beauticians.) My colleagues and I are hardly as visible as political journalists or business writers—nor, thankfully, as reviled. There are maybe a few hundred of us practicing technology journalism full time, either on staff or as freelancers, like myself. Without our experience, communications skills and dedication to accuracy, the publication you are reading and others like it would have a hard time filling their pages. And yet here we were about to be turned into computer-fodder by the very technology we covered—or so I sensed nervously between the bytes.

The *Journal* story, by staff reporter

William Bulkeley, was ostensibly about sports journalism. Running in the "A-head" position, the paper's central column usually reserved for offbeat topics, it had a wry tone. "Semi-Prose, Perhaps, but Sportswriting by Software Is a Hit" the headline read. Added the subhead: "Reporters Sometimes Sacked, Aren't So Gleeful; Would Grantland Rice Be Fired?"

The article, appearing on March 29, 1994, detailed how a $100 PC program had replaced a $1,500-a-month sports writer at a weekly newspaper in Humphrey, Neb. This software, called Sportswriter, took reports of scores and quotes from coaches of high school football and basketball games; once the information was keyed in by a typist, the computer would spew out serviceable prose relating the outcome of the game, complete with sports cliches like "knotted" scores or teams that "jump in front." The program's author, Roger Helms, was said to be looking beyond sports. The story concluded with a quote from Helms: "A virtual TV weatherperson would be a natural—you could create an image you couldn't tell from a real person."

Not being able to tell a computer's output from a real person is the criterion by which computers could be deemed intelligent, according to the famed test English mathematician Alan Turing proposed more than 50 years ago. In Turing's text-based scheme (when graphics were still far off in the future) if a real-time teletyped dialogue misled a human into thinking that the unseen party at the other end was another human, the computer could be said to be intelligent. The jury is still out on whether some artificial intelligence (AI) program can actually fool most adults into thinking it's human—even though medical diagnostic and other expert knowledge-based systems have proven more accurate than the flesh-and-blood professionals on which they were modeled. For Sportswriter, the level of writing was described as "a little below the level of a beginning reporter," but that was enough to displace high school stringers and at least one staff reporter.

So how long before I became obsolete as a result of some Technologywriter program, capable of digesting a press release, searching the Net for related reports, and dumping out at least a trade-press-worthy story, which got the facts right—and didn't take off for lunches? My career options were limited: perhaps public relations, that sold-out refuge for reporters from which few ever return to journalism, or driving a cab (and how long before those jobs were automated out of existence?). The fear haunted me. I expected to open *Wired* one day and find that all its writers had been replaced by bots (bots are autonomous software search agents that surf the Net to find items of interest to readers), avatars and other software creations (not that it doesn't already read that way, at times). Or I would glance at the top left-hand corner of *The New York Times* and see the paper's motto had been changed to "All the News That's Fit to Process."

The idea is hardly far-fetched. The *Journal* story itself cited computer-generated stock-market summaries at the Bloomberg financial news service and customized newsletters culled from thousands of online sources by a Cambridge, Mass.-based startup firm, now defunct. I have obsessively kept track of other computer threats in the making. I followed the work of the MIT Media Lab's News in the Future research consortium under its director Walter Bender—especially in the area of customized news, with the student-personalized Fish Wrap electronic newspaper and geographically-aware PLUM (Peace Love and Understanding Machine) software bringing a local perspective to news stories about natural disasters around the world. I also learned of Columbia University computer science professor Kathy McKeown's Columbia Digital News System, providing summaries of stories from live news sources, with a specialized capability for analyzing reports on terrorist activities. Closer to home and business, a new PC application from one of the pioneers of word processing (WordStar's Seymour Rubenstein), the SuperSleuth program, can analyze all the documents on a hard drive and generate a plain English text abstract for each one. For multimedia files, too.

Most recently, I find myself having banished from my mail (and the recycling bin) all technology trade publications on paper. I prefer instead to link to the latest headlines online within minutes of their posting on dozens of technology news sites from headline-agglomeration Web sites: the human-edited, bot-generated Newslinx and 100%-bot NewsHub. I'm certain Technologywriter is just around the corner and it worries me enough to keep me up at night.

Is my dread irrational—as insists my wife (a lifestyles journalist, a specialty not likely to be mastered by machines)? Admittedly, no one has been able to synthesize a readable high-tech press release, let alone a clear expository article explaining some new technology to a nonexpert in the field. To interpret the latest developments properly, a tech journalist must know not only about prior art, current affairs and future trends, but also how much or how little a publication's readers know—tough tasks to program. So there's really no software close to making me obsolete, yet. That doesn't mean it couldn't happen in the blink of an eye.

So I had to find out what Roger Helms, Sportswriter's sire, is doing. After nearly five years without a mention of him in the press, he must be closer than anyone else to unleashing an automated journalist. With a trembling hand I pushed the digits on the telephone to call him at his residence in Minnesota.

I'm surprised and relieved when Helms tells me that he's no longer in the computer-generated journalism business. Further, he assures me: "I do not expect to hear of anything to replace journalists in my lifetime." (Helms is 47. I'm a few years older, so feeling even less threatened.) The problems are just too daunting. The Sportswriter program, written as a simple

I must admit I wouldn't mind a program that would automate the writing of this essay, while I go out and enjoy what looks like an unseasonably warm day.

script in Apple's Hypertalk hypertext software, actually sold to 150 small-town newspapers, but its limitations quickly showed. It was a clever programming feat based on a rarefied journalistic domain: "In sports, the language is intimately tied to numbers," he explains. "The numbers prompt all your thinking. This kind of software doesn't work for anything that isn't quantifiable." So even if automation comes, financial and business reporting are far more likely to succumb than technology journalism.

But wait a minute. If Helms doesn't expect anything replacing journalists in his lifetime, what about the sports reporter in the *Wall Street Journal* article? According to Helms, the paper didn't get it right. "It bore no relation to reality." Anyone automated out in the wake of Sportswriter was marginal to the news-gathering process. "A lot of these newspapers have staffs of two and-a-half writers—two full-time and one part-time—who can't go out to see every high school game. They all depend on forms sent in by the coaches." Nor was the program a great time-saver. "That was a big misconception," he admits. "Sportswriter required the time it took to input all the game information, followed by someone to spruce up the story."

Still, Helms sees computer-generated journalism meeting a need at the small-staff, low-budget end of news publishing. Especially when "expectations seem to be coming down, while the amount of information people want is growing. Getting it in unfiltered units is important to people." With the elimination of news-gathering middlemen on the Net, bringing direct access to information by readers no longer in need of professionals to interpret for them, the threshold for automated journalism could fall to well within current PC capabilities.

I'm torn by this outcome. On the one hand, journalists' abilities (including mine) are being augmented by computer-mediated news (no more papers or tech books for me). But isn't there a risk in the loss of human insight? We all could use a journalistic Alfred to keep watch on things where automated systems can't. Still, I must confess, I wouldn't mind having software write this essay—while I go off and enjoy an unseasonably warm day today. Who knows? I could run into Alfred at the race track. ◊

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MIT'S MAGAZINE OF INNOVATION
TECHNOLOGY REVIEW

MIXED MEDIA

Universal Access with Style

Better living through smarter design

UNLIMITED BY DESIGN
Cooper-Hewitt National Design Museum, New York, N.Y., through March 21.

INDUSTRIAL DESIGNER BRUCE HANNAH has a big problem with products and environments designed for what he calls the "Martha Stewart niche." This market segment, populated by 35-year-old millionaires, is just too small and exclusive. What's more, adds architect/industrial designer Tanya Van Cott, even occupants of this rarefied demographic stratum leave it by raising families and growing old. The designed world, Hannah and Van Cott argue, should be accessible to people of many different ages, levels of strength and agility, and degrees of affluence.

To celebrate the approach they advocate—dubbed "universal design" —Hannah and Van Cott have designed an engaging new exhibition for the Smithsonian Institution's Cooper-Hewitt National Design Museum in New York. In "Unlimited by Design," Hannah and co-curator George A. Covington bring together examples of universally designed interiors, consumer goods and recreation systems, all meant to enhance everyday activities. Many items on display are commercially available today; others begin to define the household of the future.

What's immediately striking is just how stylish and attractive most of this stuff is. Each of the exhibit's many rooms represents an arena of daily life. The kitchen is stocked with funky, chunky (and easy-to-grasp) cooking and eating utensils, the office outfitted with sleek,

ANDREW BORDWIN

Now we're cooking: A "universally designed" kitchen puts stuff in easy reach.

WEB SITE

Exploring Comics Space

WWW.UNITEDMEDIA.COM/EXPLORER/

Is your comics reading in a rut? Well, this site sponsored by United Media is intended to blast you out of it. Pick a comic—Dilbert, say. Today's strip appears on the screen, along with tools that let you go back and see the last couple of weeks. Now for the cool part. A set of color-coded sliders represents four defining characteristics: the age of the characters, the age of the strip, the continuity of the story line, and the "zoo factor" (extent to which characters are nonhuman). Move these sliders up and down and you will see, bobbing across the bottom of the screen, a constantly reshuffling set of icons for six or seven other comic strips that have the specified qualities.

UNITED MEDIA

Say you start with Dilbert, then raise the zoo factor and lower the continuity and the character age. Result: a selection set that includes Robotman, Peanuts, and Alley Oop. Choose Peanuts, and the Dilbert strip disappears with a gradual, peel-away effect to reveal today's adventures of Snoopy and friends. The whole point is to tinker, so now we lower the zoo factor and raise the story continuity, and get dealt a new set of choices, including Arlo & Janis and For Better Or For Worse.

OK, so it's only comics. But others would be wise to look here for a creative approach that might apply as well to weightier types of literature. You can keep up this reshuffling and sorting endlessly, but make sure you have a fast computer. The Java applet works tolerably on a 266 MHz Pentium II, but trying it on a slower machine may put you in foul humor, no matter how funny the comics.

—Herb Brody

curvaceous (and orthopedically correct) furniture. Indeed, says Hannah, one of the exhibit's prime goals is to counter the stigma of accessibility—the assumption that things designed with the needs of the disabled or elderly in mind must be ugly or awkward.

Linger in front of a display and you begin to see how universal-design principles can inform familiar objects. Take a laundry detergent bottle cap: its ridges help a shaky or arthritic hand keep its grip, its bright color contrasts with that of the bottle for better visibility, it does double duty as a measuring cup, and it pours residual soap back into the bottle, cutting down on waste and mess. Lever-style door handles (a small room showcases several versions) fit more comfortably in the hand than a knob, have a shape that indicates clearly which way they should be turned, and can be operated with an elbow if hands are unavailable.

The bathroom and kitchen showcase systems were created from the start with accessibility in mind. The MetaForm Personal Hygiene System, designed by a team led by Gianfranco Zaccai at the consulting firm Design Continuum, was conceived as a tool to help the elderly and disabled live more independently. The result is a set of modules, or "nodes," that mount between the studs of a wall. Both the sink node—complete with lighted mirror, medicine cabinet, outlets and drawers—and the toilet node—which includes a built-in bidet and folds into the wall for automatic sanitization—can adjust vertically to accommodate everyone from wheelchair users to small children to NBA centers.

The Universal Kitchen was dreamed up by a team of students at the Rhode Island School of Design (RISD). With help from faculty, industry and project advisors (including Julia Child), the RISD group reinvented the kitchen. They ignored design conventions that require meal preparers to stoop, stretch or climb on counters. All appliances rest at a comfortable height; dishwashers, for example, double as cabinets or pop vertically out of an island countertop. Lazy-susan refrigerator shelves and pull-out cabinet shelves render food and dishes reachable. And, in a bow to the American affection for pasta, the kitchen island includes a basin of

P E R F O R M I N G   A R T S

INTERNATIONAL PRODUCTION ASSOCIATES

Digitally transcendent: Opera plus high-tech animation equals surreal high art.

3-D Opera Glasses

Over the years, 3-D movies have tended toward the cheesy. What can you expect from an entertainment medium requiring a room full of viewers to watch through cheap cardboard-and-mylar glasses just to get some illusory sense of depth? As a medium for art, might as well try playing classical theater to an audience wearing funny hats.

Then again, *Monsters of Grace*, a self-styled "digital opera in three dimensions," does make use of those goofy cardboard polarizing specs, albeit designer ones donated by l.a. Eyeworks, combining them with the latest in computer animation technology to create a distinctly high-art multimedia event. This historic production—now concluding a 28-city tour of North America—reunites designer-director Robert Wilson and composer Philip Glass, whose 1976 collaboration *Einstein on the Beach* is a cultural landmark.

Though much praised abroad, Robert Wilson's theatrical meditations on space and time have seldom been seen by American audiences—partly because of the huge expense of mounting them. Producer Jedediah Wheeler suggested a 3-D digital animated film as a more portable means of disseminating Wilson's vision. Live performances by Glass and his musical and vocal ensemble accompany the 78 minutes of visuals, which constitute the first ever feature-length movie using stereoscopic, 3-D animation.

INTERNATIONAL PRODUCTION ASSOCIATES

Seeing whole: Finally, there's a classy use of those cheap mylar lenses.

Why work with something as gimmicky as 3-D? Attending a performance of *Monsters of Grace* at the beginning of its current tour at the Brooklyn Academy of Music (an incomplete version made its debut last April in Los Angeles) provides the answer. The procession of surreal imagery in 13 tableaux—which this April will be seen again in Los Angeles and then in Portland, Sacramento, Berkeley, Ann Arbor, and finally Toronto—is positively Wilsonian. Still, the high-resolution, 70 mm film provides a reach even grander than the stage-front-to-stage-rear palette of lighting effects and dream-like pantomimes for which Wilson is known.

A computer-generated child pedals a bicycle seemingly out among the glasses-wearers at an impossibly slow pace. A pure white ball of texture hovers above the audience and mutates into a dozing polar bear. A giant synthetic hand juts out beyond the proscenium, appearing to originate just a few rows ahead of the viewer. In this truly remarkable piece based on the 13th century mystical poetry of Jalaluddin Rumi, the fingers floating this side of the theatrical arch are digitally transcendent, in every sense.

—Steve Ditlea

piped-in boiling water, fitted with a lightweight basket that lifts out easily—no more burning yourself trying to drain the heavy pot of spaghetti into the sink.

Though the RISD kitchens and the MetaForm bathroom are prototypes, they are technologically feasible. Looking at the gallery around him, Hannah gives voice to what is perhaps the exhibition's most important message: "There's nothing here that can't be done tomorrow."

—Rebecca Zacks

Net Nuggets

Movie database: Can't remember who provided the voice for 2001's HAL 9000? Wondering if the director of Jaws 3-D ever worked again? Go here for answers to those and pretty much any other movie trivia questions that might be gnawing at you. No more scouring the mental files for a forgotten title or actor—this easy-to-use database covers more than 180,000 movies, providing extensive filmographies for cast and crew members, plot summaries, reviews, box office grosses, quotes, awards and more. It's an orgy of pop-culture information. **www.imbd.com**

—RZ

Red Rock Eater News Service: Join this mailing list for an antidote to the cheerleading that characterizes so much of the rhetoric about information technology. Phil Agre—the UCLA communications professor who runs this list—recommends books and Web sites, and writes mind-opening essays about computers and society. Agre's no Luddite but he has high standards for how technology should serve people rather than the reverse. To subscribe, e-mail: **rre-on@lists.gseis.ucla.edu.**

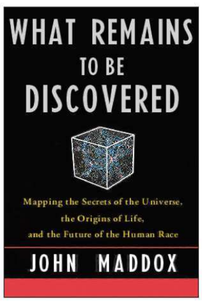
—HB

Acronym finder: This no-frills site from the University of Oslo identifies any acronym you type, from the technical to the bureaucratic to the obscene. Keep this Rosetta stone open in a corner of your screen as you thrash your way through the murk of abbreviations. **http://habrok.uio.no/cgi-bin/acronyms**

—HB

News of Death, Greatly Exaggerated

WHAT REMAINS TO BE DISCOVERED: Mapping the Secrets of the Universe, the Origins of Life, and the Future of the Human Race
by John Maddox
The Free Press, 434 pp., $26



IN HIS CONTROVERSIAL BOOK *The End of Science,* John Horgan suggested that the era of great scientific discoveries is over: Exploring the solar system or the human genome may keep us busy for a while, but our findings probably won't require the invention of radical new theories on a par with those of Copernicus, Darwin or Einstein. After all, how much has happened in astronomy since the work of Edwin Hubble in the 1920s, or in genetics since James Watson and Francis Crick's description of DNA in the 1950s, to fundamentally change the way we see the universe and our place in it?

When Horgan's book came out in 1996, I was a reporter at *Science* magazine covering developmental biology, a discipline undergoing a stunning metamorphosis thanks to new techniques for manipulating genes. I knew better, therefore, than to swallow Horgan's idea whole. I suspected that readers familiar with other fields would scoff just as loudly, but I lacked detailed evidence. Now John Maddox, one of "the last great scientific polymaths" (in the estimation of Richard Dawkins), has assembled that evidence into a captivating, highly readable book.

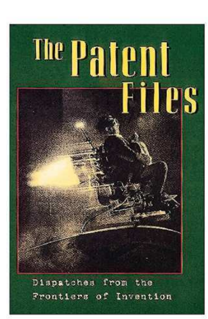
In many of his editorials in the prestigious research journal *Nature*, which he led for 23 years, Maddox played court cartographer, assembling scientists' field reports into maps of the territories of the natural sciences that were being colonized successfully and those that remained terra incognita. In *What Remains To Be Discovered*, Maddox focuses on the empty parts of the map, those denoting woeful gaps in scientists' understanding of such basic matters as the nature of the Big Bang and the connection between electromagnetism, the strong and weak nuclear forces and gravity. If many fields seem to be caught in the doldrums, with their last big organizing ideas having appeared more than a generation ago, it's not a sign of the end of science, but merely a measure of the work left undone, Maddox chides.

"The truth is that the sheer success of science in the last half-millennium has engendered a corrosive impatience," Maddox writes. "We too easily forget how recent are the empirical and theoretical foundations of present understanding. Prudence, or merely good manners, would dictate a seemly recognition that they may also be incomplete." The news of the death of science has been greatly exaggerated.

A Bigger Pain in the Ass

THE PATENT FILES: Dispatches from the Frontiers of Invention
by David Lindsay
The Lyons Press, 248 pp., $19.95

AMIDST ALL THE HYPE ABOUT "FUTURE firms," "innovation management" and "technoleverage," it's easy to forget that innovation starts small. The slightly mad inventor tinkering in his cellar, once a cultural hero in the United States, has been overshadowed by the product development team working in a billion-dollar research park. But Edison started out as an itinerant telegraph operator, and even today, unconventional ideas are likeliest to pop up in disestablishmentarian places—or so David Lindsay is convinced.



In *The Patent Files,* a collection of columns from the alternative weekly newspaper *New York Press,* Lindsay proves that the oddball inventor types, the loners nursing their revolutionary gadgets in the face of skepticism, are alive and well. Lindsay's guide to this subculture is the U.S. Patent Office, where "stacks of documents gather the smells of nervous men." The patented ideas that succeed in the marketplace are vastly outnumbered by those that die on the drawing board, Lindsay finds, making the patent files a directory of eccentric, embittered geniuses.

His essays profile a few of these misfits in all their earnest, often hilarious humanity. Many have genuinely good ideas that simply haven't caught on—at least not yet. Winston MacKelvie of Knowlton, Quebec, for example, dreamed up DrainGain, a tank that goes under the sink and captures the thermal energy in hot water that would otherwise dissipate in the sewer.

But not all the innovators Lindsay tracked down have a practical bent. For every MacKelvie there is a Joseph Newman, a Mississippi man who invented the plastic-covered barbell but failed to win a patent for his perpetual motion machine, made from magnets, coils of wire and 116 nine-volt batteries. Newman told Lindsay that Comet Shoemaker-Levy's collision with Jupiter signified that the Apocalypse would begin on August 21, 1994. "I for one can find no cause to blame him" for being a doomsayer, Lindsay writes. "I mean, if you had invented a perpetual motion device, developed a unified field theory and discovered that you were the Messiah... wouldn't a trivial detail like a rejection from the Patent Office confirm for all time the monkeyshine of man?"

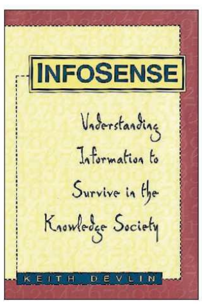
In Lindsay's lighthearted essays, which climax with his own adventures in intellectual property law, inventions and patents become portraits of their times and of their doggedly determined authors. Lindsay relates in a 1996 column that as "a perverse little thought experiment...[and] protection in an age of genetic racketeering," he once sought a patent on himself. When he

found out how much the paperwork would cost, he decided instead to copyright himself as a musical composition, with the frequency of the tones based on the sequence of nucleotides A, C, G, and T in his DNA. When the Register of Copyrights thwarted even this attempt—on the grounds that Lindsay's DNA was not an "original and creative product of human authorship"—he remained unfazed. His comeback line could be the underground inventors' motto: "What doesn't kill me makes me a much bigger pain in the ass."

What Meets the I

INFOSENSE: Understanding Information to Survive in the Knowledge Society
by Keith Devlin
W.H. Freeman, 256 pp., $24.95

AMERICAN AIRLINES FLIGHT 965 FROM Miami to Cali, Colombia, rammed a mountainside in December 1995, killing all 159 on board. The cause: a disconnect between information and context. Air traffic controllers in Cali radioed the plane to fly toward a nearby beacon named "Rozo." From a computerized list of beacons beginning with the letter R, the crew selected the first—by convention, the nearest. But in this case, unbeknownst to the crew, the list began with "Romeo," 100 miles to the left in Bogota. The autopilot followed the faulty directions, leading to what accident investigators call "controlled flight into terrain."



Humans only acquire data or "little-i information" and make it into useful understanding or "big-I Information" by assuming a context for it, and the results can be disastrous if they assume the wrong one, mathematician and math popularizer Keith Devlin warns in *InfoSense.* In the terms of the "situation theory" developed by Devlin and his colleagues at Stanford University's Center for the Study of Language and Information, the American Airlines crew sealed their doom by relating a piece of little-i information (the letter R) to a "constraint" or context (the convention of listing beacons from nearest to farthest) that was different from the constraints observed by the programmers of the flight mangement computer.

"We are so used to dealing with information in our everyday lives...that we often fail to see the complexities involved," Devlin observes. Using examples as gripping as the American Airlines disaster and as mundane as a poorly designed ATM screen, he argues that a situation-theory view of information can forestall misunderstandings in the cockpit, the office or the operating room.

Using situation theory, Devlin and his colleagues have mathematically validated a number of interesting strategies for boosting productivity and innovation within a group. For example, it turns out that optimum team size is two or three; as more members join, the opportunities for misunderstandings multiply far faster than does brainpower. And "information immersion"—surrounding a team with relevant data, whether stored on low-tech whiteboards or on sophisticated "knowledge maps" running on corporate intranets—can make communication more efficient by increasing the overlap between team members' individual contexts, Devlin shows. Readers immersing themselves in *InfoSense* will find there is far more to information than meets the I.

Burn, Baby!

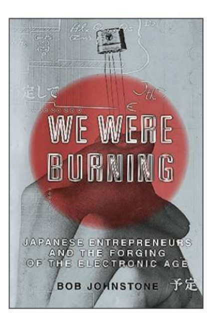
WE WERE BURNING: Japanese Entrepreneurs and the Forging of the Electronic Age
by Bob Johnstone
Basic Books, 422 pp., $27.50

A BELIEF STILL PREVALENT IN AMERICA has it that Japanese manufacturers' stunning successes in the 1970s and 1980s can be traced to the industrial policies of MITI, the Ministry of International Trade & Industry. By bringing big firms together into research and development consortia focused on problems like large-scale integrated (LSI) circuits, the story goes, MITI enabled Japanese companies to gain market share in new industries faster than American firms with their go-it-alone approach. The Clinton administration admired this model so much that by 1996 it had given $1.3 billion to the U.S. Display Consortium, a Silicon Valley group formed to take back the lead in the domestic market for flat-panel displays.

The reality, however, is almost the opposite, at least in the consumer electronics industry, freelance technology journalist Bob Johnstone argues in his important new book *We Were Burning* (a Japanese expression meaning, "We couldn't wait; we had a can-do spirit"). Japanese inventor-entrepreneurs were simply the first to see the commercial possibilities in American-born technologies such as metal oxide semiconductor (MOS) chips and liquid crystal displays (LCDs), enabling Japanese electronics firms to beat American companies at their own game.

The most visionary of the dozen or so Japanese Edisons profiled by Johnstone is Sharp's Sasaki Tadashi, who decided in 1964 that his company (then Hayakawa Electric), which was forbidden by MITI to make computers, should develop portable calculators equipped with LSI circuits. Texas Instruments shelved its prototype microchip-powered pocket calculator in 1967, seeing no demand for it in a market dominated by electromechanical adding machines. But Sasaki remained convinced that Sharp could replace the abacus used by every shopkeeper and housewife in Japan. He persuaded Rockwell International to supply MOS chips for the 1.4-kg Microcompet desktop calculator, which Sharp unveiled in 1969.

By the time of Sasaki's retirement in 1985, Sharp had reduced the price of a calculator by a factor of 100, Johnstone relates. "More importantly for the future, [the company] had turned itself into a technological powerhouse, with all the skills needed to produce a continuous stream of innovative new products, such as the Wizard personal organizer and the ViewCam video camcorder." He suggests that the American image of the Japanese as conformists incapable of originality amounts to little more than egotism and racial prejudice. "It is hard to imagine such faceless clones as brave risk takers, betting their companies on some new and unproven technology," Johnstone writes. "And yet, beyond question that is what they have repeatedly done." ◊



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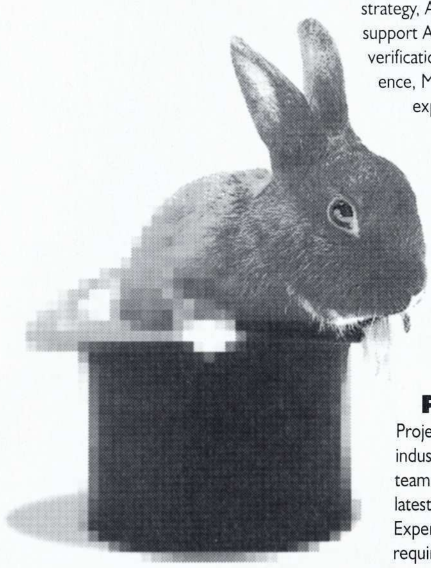

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The remarkable Auto Starter® eliminates the need for dangerous jumper cables and can provide independent power for a variety of uses.

Imagine this...after a long flight home, you arrive at the airport parking lot, get in your car and turn the key. Nothing happens, not even a click. Guess what? Your car battery's drained. It's cold, dark and you're alone. Do you flag down a stranger and hope he has jumper cables? Do you walk back to the airport, phone a tow truck and wait? No...you simply reach into your glove box and take out your Auto Starter®. You plug it into your car's cigarette lighter and, in a matter of minutes, you're on your way.

A good start. These days, cars have complex electrical systems which increases the risk that someday you'll find your car's battery drained...no horn, no lights, not even a click from the solenoid. Before Auto Starter, you either had to call a tow truck or try to get a jump from another vehicle. Jumper cables, even heavy-duty ones, are dangerous and involve getting under the hood. Plus, there has to be another car around to provide the jump. If the cables are not connected correctly they can damage your car's expensive electrical system or, even worse, cause an explosion. With Auto Starter, you don't need a jump—you don't even have to open the hood. You simply plug the unit into the cigarette lighter, wait a few minutes and you're on your way. Leave the unit plugged in for 30-120 minutes while driving and it recharges automatically.

The five-amp sealed alkaline battery operates under extreme temperatures, from sub-zero to 120 degrees. It is less than eight inches long, so it stores easily in your glove box. Once it's charged, Auto Starter will retain the power to start your car for five years. It is the easiest, most convenient protection you can own.

The Auto Starter eliminates the need for another car to give you a jump, and gives you a portable 12-volt DC power supply!

- *No getting out of your car*
- *No opening the hood*
- *No jumper cables*
- *No tow trucks*
- *No flagging down strangers*
- *Portable power...anywhere*

Portable power. Auto Starter has many other uses. It's an independent 12V DC power supply that can operate TVs, radios, cellular phones and laptops. Almost any appliance that runs off of an adapter can operate independently with Auto Starter.

Auto Starter also makes it easier to work on your car. Plug it in before you change the car battery, and you won't have to reprogram your car's clock, radio or alarm system. You wouldn't think of driving around without a spare tire—why not have a spare battery and alternator that fits right in your glove box?

Try it risk-free. Considering the cost of a tow, Auto Starter will pay for itself the first time you have a problem. This product is backed by a one year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If you are not fully satisfied for any reason, return it within 30 days for a full refund, "No Questions Asked."

We knew the storm was coming before the Park Rangers did"

All Hazards Weather Radio provides continual weather and emergency monitoring and has a variety of helpful features.

Until now, there has been no single source for immediate, comprehensive weather and emergency information, available to the public, in advance of TV and radio bulletins. Oregon Scientific, a leader in personal electronics, has created a special radio that is ideal for traveling, as well as for campers, hikers and everyone who needs to be prepared for weather emergencies in the great outdoors. It monitors the U.S. Emergency Alert System and automatically seeks all seven frequencies used by the NOAA (National Oceanic and Atmospheric Administration) Weather Radio system. This network broadcasts 24-hour weather forecasts, weather-related travel conditions and warnings about imminent severe weather conditions.

Automatic alert. In the event of special warning broadcasts, the radio's innovative alert system automatically activates a loud tone

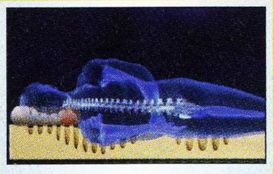
UPDATES AROUND THE CLOCK

- NOAA Weather Radio Network
- U.S. Emergency Alert System
- Federal Emergency Management Agency (FEMA)

"For years I had trouble sleeping restfully—now I know the problem was in my mattress!"

NatureSleep™Platinum features comfort zones that match your body's shape and promote restful, therapeutic sleep.

Traditional mattresses leave your lower back and legs unsupported and hinder proper circulation. Even expensive waterbeds, which are supposed to distribute weight evenly, fail to support the body properly. Your spine arches downward, in a position specialists refer to as "hammocking," causing excessive strain on the back. Scientists and doctors agree that the ideal position is a neutral body posture in which the different parts of the human body are supported individually and evenly. This is the secret behind NatureSleep Platinum, the revolutionary product that turns any bed into the ideal sleep surface.



The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure.

Scientific solution. Anatomic Concepts, a medical products research and manufacturing company, has designed the ultimate mattress pad. Using research originally

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and a flashing red LED indicator. If the radio is in silent standby mode, it even turns on the speaker. Emergency bulletins might include alerts for tornadoes, hurricanes, earthquakes, ice and snow storms, thunderstorms and other severe weather as well as other emergencies that require immediate public notification.

Important features. The radio incorporates a variety of special features geared for outdoor use. These include a built-in analog compass, ambient temperature display and an audible/visual Freeze Warning Alert. The digital display incorporates a clock with alarm and snooze controls. A switch lets you turn the speaker to ON or MUTE, or you can set the unit to stand-by mode. The unit's water-resistant case is rugged and durable, and there's even a built-in belt clip and desktop stand. Its compact, lightweight design makes it ideal for almost any situation, and it operates on 3-AA batteries.

Try it risk-free. The All Hazards Weather Radio comes with a one-year manufacturer's limited warranty and Comtrad's risk-free home trial. If for any reason you are not satisfied, simply return it within 90 days for a full refund.

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conducted for hospitals, this innovative company developed an effective, affordable way to transform any mattress into a specially-designed sleep surface that closely matches the shape of the human body. It features a patented five-zone sleep surface that holds the body in a neutral posture and redistributes pressure during sleep.

✔ *A unique, high support factor design for more comfortable, restful sleep.*

✔ *Comfort zones match your body shape. Built-in lumbar support reduces spinal stress and backaches.*

Comfort zones. The distinct comfort zones in NatureSleep Platinum have revolutionized the sleep-product industry. They reduce sleep stress—especially strain on the spine—and cradle those areas of the body prone to increased pressure. Until now, only the most expensive and most advanced mattress products featured this degree of technology, but now you can get it without even buying a new mattress.

Installs in seconds. NatureSleep Platinum fits right over your existing mattress, uses normal sheets and turns any bed into an anatomically-correct sleep surface. The five comfort zones have been created using a computer-designed grid pattern and are engineered to accommodate people of all heights and sizes.

Risk-free. Try it for yourself, it comes with a one-year manufacturer's limited warranty and Comtrad's exclusive risk-free home trial. If for any reason you are not completely satisfied, return your purchase within 90 days for a full refund, "No Questions Asked."

The efficiency of ceramic warmth combines with oscillation to create the perfect heater...

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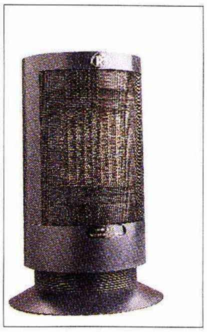
This compact heater uses a genuine ceramic heating element and an oscillating fan to eliminate cold spots and provide intense warmth throughout an entire room!



If you could build the perfect heater, what features would it have? A safe, yet effective, heating element? A thermostat that would let you select a desired comfort level? An effective way to disperse the heat throughout an entire room? Safety features like automatic tip-over and overheat protection?

Royal Sovereign recently unveiled a remarkable new heater that combines a ceramic heating element with a solid-state thermostat and an oscillating fan—its called the RST-1200 Oscillating Heater.

Ceramic advantage. The RST-1200 utilizes a genuine ceramic heating element. Ceramic elements are known to be a very efficient and effective heating method. Ceramic heaters do not burn air—therefore, they do not cause any odors or produce any unwanted side effects. Even more important is the fact that the RST-1200 does not get hot to the touch—so it is not a fire hazard.

Control your climate. The RST-1200 has an electronic thermostat that lets you choose your own comfort level. Simply set the dial to the appropriate temperature, and the RST-1200 will automatically maintain that comfort level. It provides even, uniform heat—without irritating hot/cold cycles.

Spread warmth throughout a room. The RST-1200 oscillates over a range of 70°. A high-velocity fan disperses the intense warmth resulting in even distribution of the heat. The RST-1200 will eliminate cold spots, even in those rooms with poor ventilation!

The oscillating difference.

The RST-1200 is unlike ordinary space heaters. Because it oscillates over a range of 70°, the RST-1200 spreads the warmth created by its genuine ceramic heating element evenly throughout your room, eliminating cold spots. And with its solid-state thermostat, you can set a specific temperature, and the RST-1200 will maintain it effectively and efficiently.

Safety features. The RST-1200 may be the safest space heater you can buy. Its cool-touch cabinet prevents the RST-1200 from being a fire hazard. The RST-1200 also has built-in, automatic overheat and tip-over protection. The unit will shut off if tipped over, airflow is blocked or anything is spilled on it. A red safety light indicates that the unit has shut itself off for some reason. The RST-1200 is so safe you can let it run 24 hours a day, worry-free!

Try it risk-free. The RST-1200 Oscillating heater is backed by Comtrad's risk-free trial. Try it, and if you are not completely satisfied, return it within 90 days for a full refund. It also comes with a one-year manufacturer's limited warranty.

A. Auto Starter®	$49.95	$6 S&H
Buy two or more	$39.95	each
B. Portable All Hazards Weather Radio	$79.95	$9.95 S&H
C. NatureSleep™ Platinum:		
Twin	$59.95	$8 S&H
Double	$89.95	$10 S&H
Queen	$99.95	$12 S&H
King	$119.95	$14 S&H
D. RST-1200 Oscillating Heater	$99	$9 S&H

Please mention promotional code 5003-14855.

For fastest service, call toll-free 24 hours a day

800-992-2966

To order by mail, send check or money order for the total amount including S&H. To charge it, enclose account number and exp. date.

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COURTESY OF *THE SATURDAY EVENING POST*

Sounding an Alarm in the Sky

A "ridiculously simple" device keeps airplanes aloft.

AIRPLANES ARE LARGELY THE TOYS OR TRANSPORTERS OF THE middle and upper classes. But one man's childhood of poverty paved the way for a clever gadget that helps pilots keep their planes in the air.

Born in New York in 1918, Leonard M. Greene was the youngest in a family of five caught in the post-World War I depression. Living on $20 a month, the family had no money for toys, so a 5-year-old Greene began to invent his own playthings. He rejuvenated spent batteries in salt water, built a lighted wagon, salvaged a sewing-machine motor—all with a "trash-can set" of a children's encyclopedia for reference and inspiration.

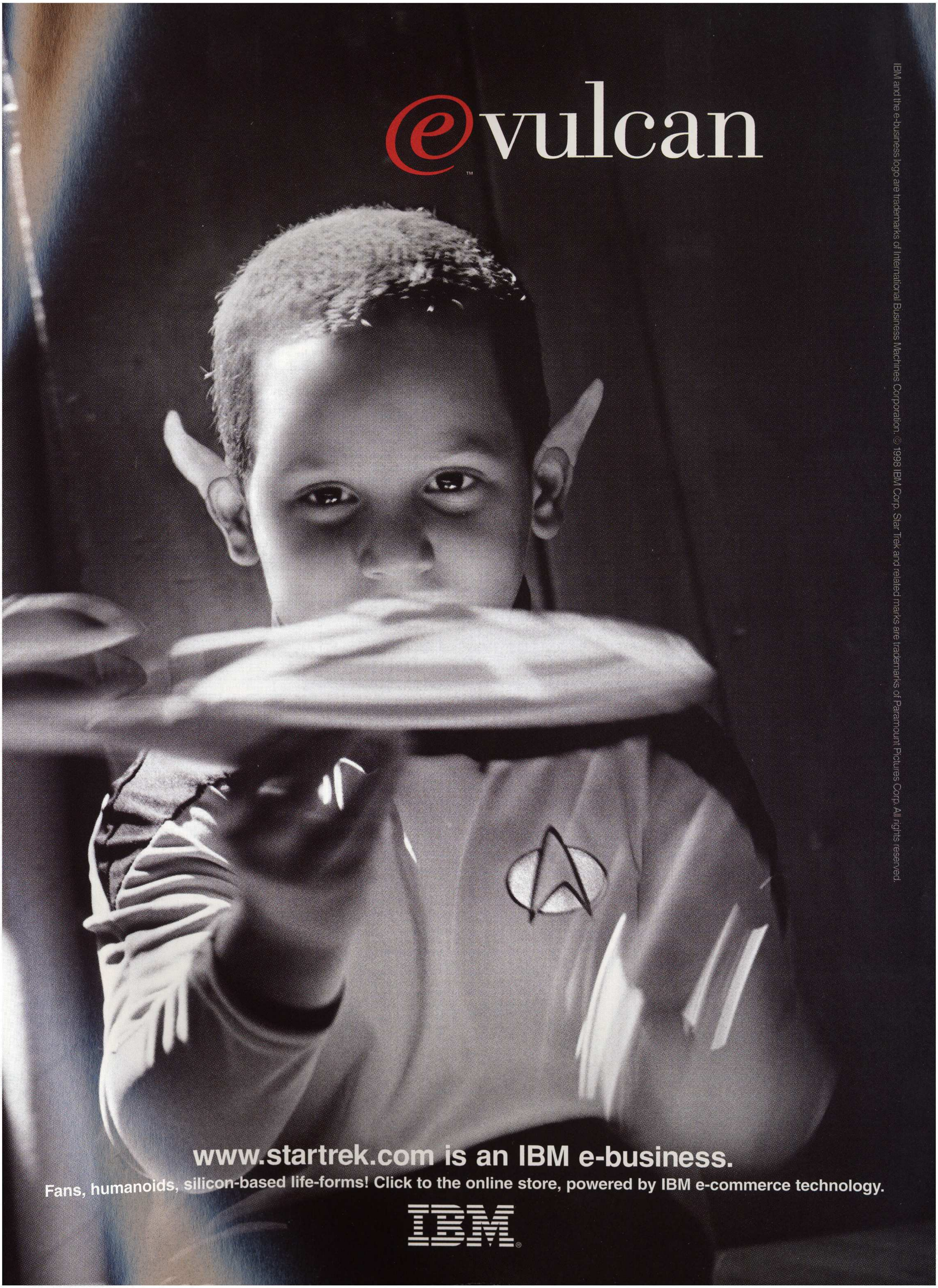
Greene called on the same ingenuity at the age of 19, after he and a friend witnessed the nose-first crash of a small plane at a New York airfield. The pilot, Greene's friend explained, was trying to climb too steeply and caused his plane to lose lift, or "stall." At that time, stall accidents caused more than half of all aviation deaths.

As a plane tilts up, the air splits (to flow above and below the wing) at a point progressively farther down along the curve of the wing's leading edge; if that point is too far down, the air no longer flows properly and lift is lost. So, Greene reasoned, why not put a small vane protruding forward at a spot slightly above the critical point? When the air began to hit the wing at a dangerous angle it would flip the vane up—a contact on the vane could complete an electrical circuit that honked a horn and flashed a warning light in the cockpit.

Greene built his first stall detector from pieces of an alarm clock, and earned a pilot's license so he could make test flights himself. In 1946, he founded the Safe Flight Instrument Corp. to build the warning system. The $15-to-$25 device, described by one writer as "ridiculously simple in conception and construction," was hailed in a 1947 *Saturday Evening Post* story as possibly "the greatest lifesaver since the invention of the parachute."

Today, you can still see Greene's simple vane on some commuter flights, but more often you see its complex descendant on the fuselage. Safe Flight continues to supply air-safety technology to major air carriers, the U.S. military and aircraft manufacturers worldwide. ◊

***Technology Review* welcomes suggestions for Trailing Edge.** If yours is selected, you will win a year's subscription to *TR*. This issue's winner, University of Illinois chemical engineering professor William S. Hammack (hammack@netbox.com), interviewed Leonard M. Greene in 1998. Send a few paragraphs to: Trailing Edge, *Technology Review,* MIT Building W59-200, Cambridge, MA 02139; or e-mail: trailingedge@techreview.com.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